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Nearshore/Tideflats Remedial
Investigation. Volume 1

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Prepared for

Washington State Dept. of Ecology, Olympia

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PREPARED FOR:
WASHINGTON STATE DEPARTMENT OF ECOLOGY
AND U.S. ENVIRONMENTAL PROTECTION AGENCY

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TETRA TECH

TC-3752
Final Report

COMMENCEMENT BAY NEARSHORE/ TIDEFLATS REMEDIAL INVESTIGATION

Volume 1

by

Tetra Tech, Inc.

for

Washington State Department of Ecology
and U.S. Environmental Protection Agency

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1.0 INTRODUCTION

1.1 BACKGROUND

In December, 1980, in response to significant public health and environmental threats associated with the release of hazardous substances from uncontrolled waste sites and from chemical spills, Congress passed the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). One result of CERCLA was the establishment of a "Superfund" to finance investigations of the hazardous waste problem and to fund investigations and cleanup of the most seriously contaminated sites. The U.S. Environmental Protection Agency (U.S. EPA) was delegated the lead role to work with state and local agencies to coordinate and implement programs authorized by CERCLA.

On October 23, 1981, the U.S. EPA announced an "interim priority list" of 115 top-priority hazardous waste sites targeted for action under Superfund. Commencement Bay, located in the southern Puget Sound region, was listed as the highest priority site in the state of Washington and one of the 10 highest national priority sites federal funding of remedial action under CERCLA. The Commencement Bay site was divided into four areas: the Deepwater, the Nearshore, the Tideflats Industrial, and the South Tacoma channel.

On December 30, 1982, U.S. EPA proposed additions to the national priority list. The list increased to 418 hazardous waste sites ranked by their potential threat to public health and the environment. On this subsequent Superfund list, the Nearshore and the Tideflats Industrial areas were designated as a separate project, as was the South Tacoma channel, The Deepwater area was eliminated as a priority site because water quality studies indicated less contamination in that area than was initially suspected. On September 6, 1983, U.S. EPA published and promulgated the first official National Priority List (NPL) of 406 hazardous waste sites, including the Commencement Bay Nearshore/Tideflats area.

On April 13, 1983, U.S. EPA announced that an agreement was reached with the Washington Department of Ecology (WDOE) to conduct a remedial investigation of the hazardous substance contamination in the Nearshore/Tideflats Industrial areas of Commencement Bay. Under the Cooperative Agreement, the WDOE was delegated the lead role in the investigation.

1.2 SITE DESCRIPTION

Commencement Bay is an embayment of approximately 9 mi^2 in southern Puget Sound, Washington (Figures 1.1 and 1.2). The bay opens to Puget Sound in the northwest, with Tacoma situated on the south and southeast shores. The mean tidal range in Commencement Bay is 8.1 ft, with a diurnal range of 11.8 ft and an extreme range of 19 ft (COE 1983). Residential portions of northeast Tacoma and the Browns Point section of Pierce County occupy the north shore of the bay. Ownership of the shoreline is vested in the Port of Tacoma, the city of Tacoma, Pierce County, the state of Washington,

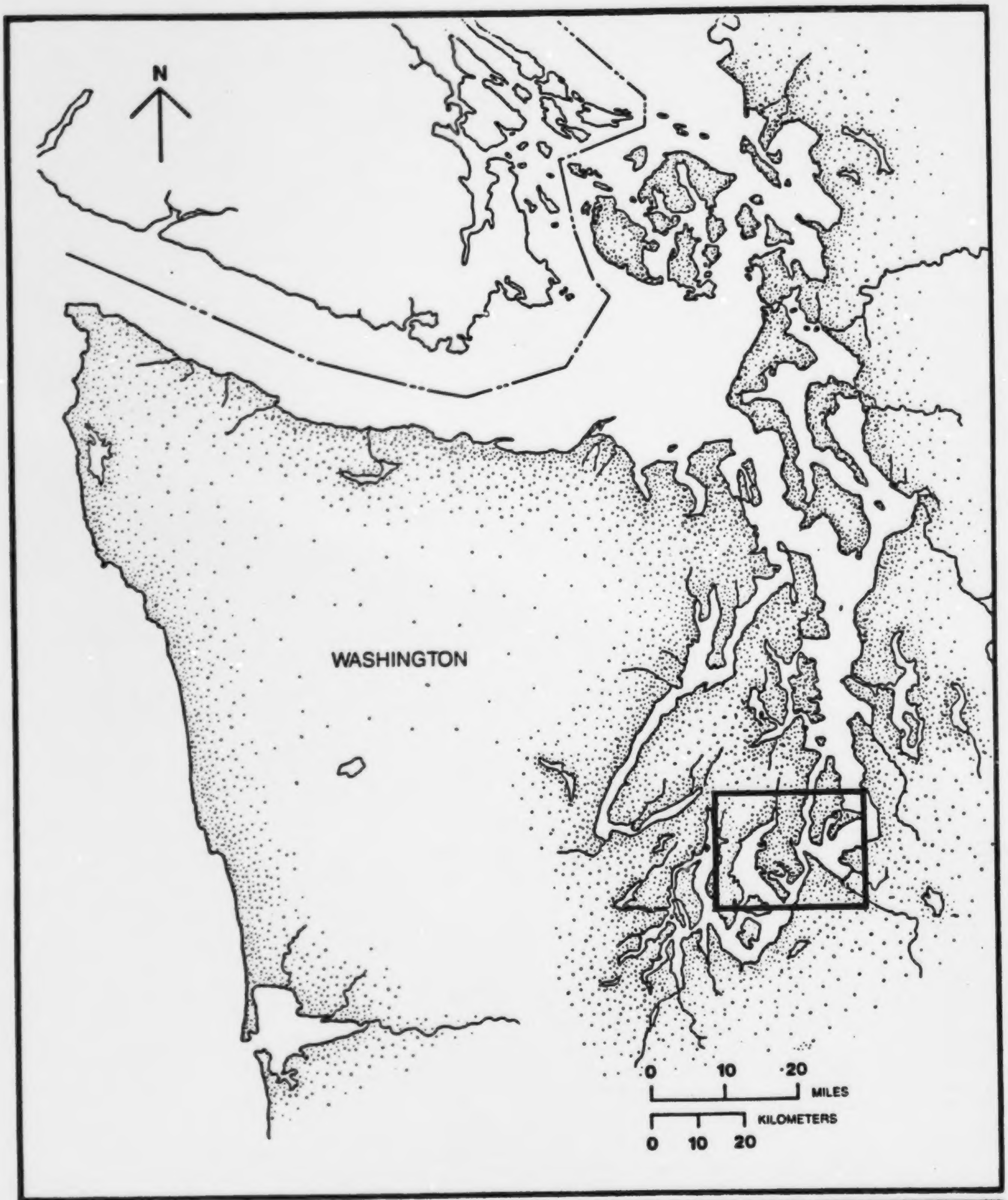

N
WASHINGTON
0
10
20
MILES
KILOMETERS
0
10
20

Figure 1.1. General location of study area in Puget Sound.

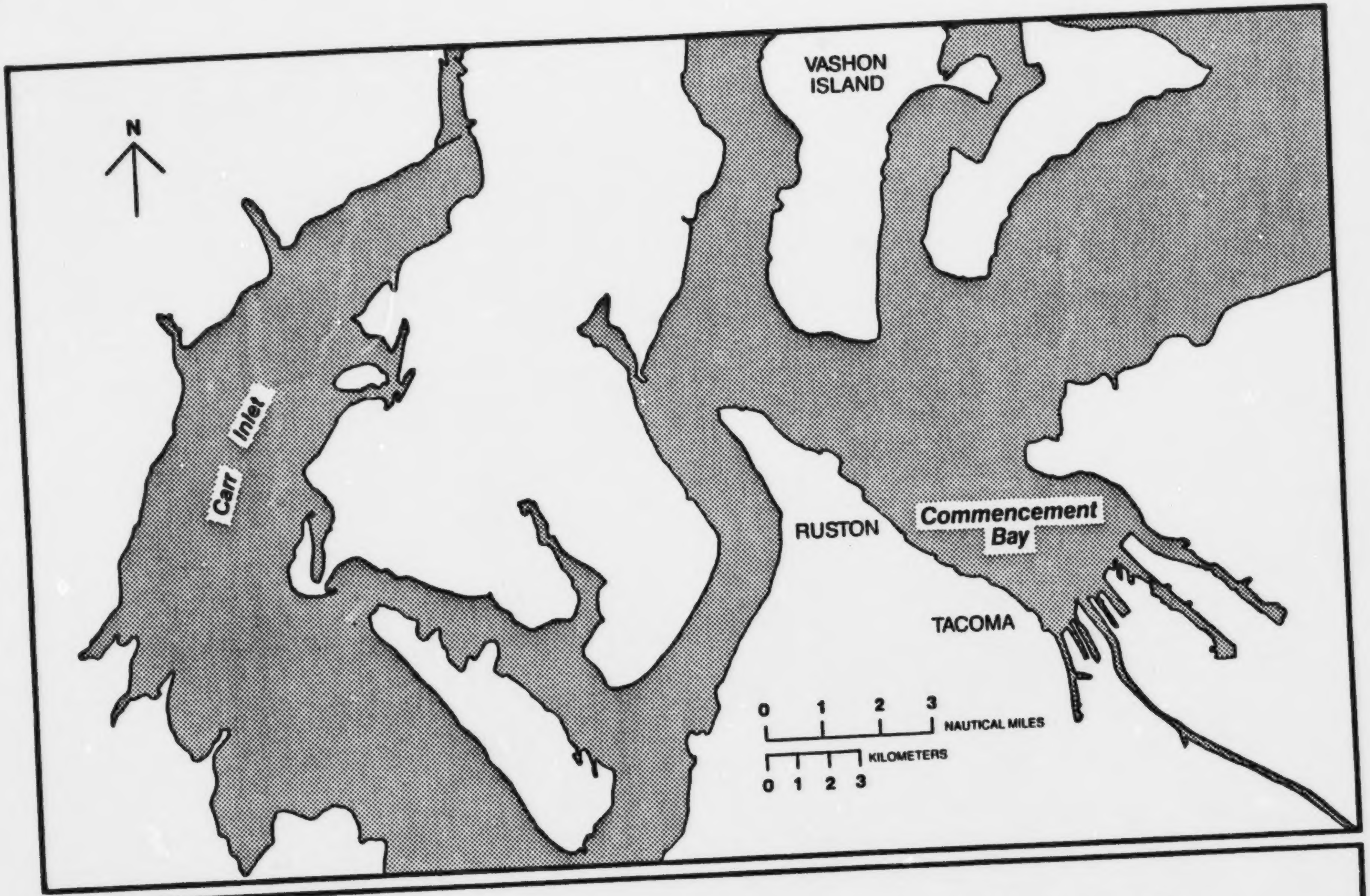

N
VASHON
ISLAND
Carr
Inlet
RUSTON
Commencement
Bay
TACOMA
0 1 2 3 NAUTICAL MILES
KILOMETERS
0 1 2 3

Figure 1.2. South and southcentral Puget Sound showing locations of Commencement Bay and Carr Inlet.

the Puyallup Indian Tribe, and numerous private parties. Much of the publicly owned land is leased to private industrial and commercial enterprises.

The Nearshore area is defined as the area along the Ruston Way shoreline from the head of City Waterway to Pt. Defiance, including all waters with depths less than 60 ft. The Tideflats area includes Hylebos Waterway, Blair Waterway, Sitcum Waterway, Milwaukee Waterway, St. Paul Waterway, Middle Waterway, City Waterway, and the Puyallup River upstream to the I-5 highway bridge (Figure 1.3). The project boundaries are shown in Figure 1.3.

1.3 NATURE AND EXTENT OF PROBLEM

Urbanization and industrial development of the Commencement Bay area began in the late 1800s. At that time, the south end of the bay was primarily tideflats formed by the Puyallup River delta. Since their inception in the 1920s, dredge and fill activities have significantly altered the estuarine nature of the bay. Intertidal areas were covered and meandering streams and rivers were channelized. Numerous industrial and commercial operations located in the newly filled areas of the bay. These included pulp and lumber mills, shipbuilding, shipping, marinas, chlorine and chemical production, concrete production, aluminum smelting, oil refining, food processing, automotive repair services, railroad operations, and a number of other storage, transportation, and chemical manufacturing companies. The documented waste management practices of these operations included landfills, open dumps, chemical recycling and reclamation, and on-site storage and treatment facilities.

A smelter (ASARCO) has been located in the nearshore area close to Ruston since the late 1800s. The plant, operational until March, 1985, generated substantial amounts of slag containing various metals. This slag was deposited along the shoreline near the plant and used as fill, riprap, and ballast material in the Tideflats area. The slag material was also utilized to produce commercial sandblasting material used widely throughout the study area. While the hazards of the slag remain undetermined, it contains high concentrations of toxic metals, primarily arsenic.

Since initial industrialization of the Commencement Bay area, hazardous substances and waste materials have been released into the terrestrial, freshwater, groundwater, and marine environments. Discharges and dumping of solid and liquid, organic and inorganic waste materials, and contamination from airborne wastes entering via surface and groundwaters have modified the chemical quality of the waters and sediments in many portions of the area. These pollutants include metals (e.g., arsenic, lead, zinc, copper, mercury) and organic compounds [e.g., polychlorinated biphenyls (PCBs), dibenzofurans, chlorinated pesticides, plasticizers (phthalates), and polynuclear aromatic hydrocarbons (PAH)].

Pollutant loadings in the Commencement Bay site originate from both point and nonpoint sources. Industrial surveys conducted by the Tacoma-Pierce County Health Department and the Port of Tacoma indicate that there are over 281 industrial activities in the Commencement Bay Nearshore/Tideflats area. Approximately 27 of these are NPDES-permitted discharges, including two sewage treatment plants. Nonpoint sources include two creeks; the

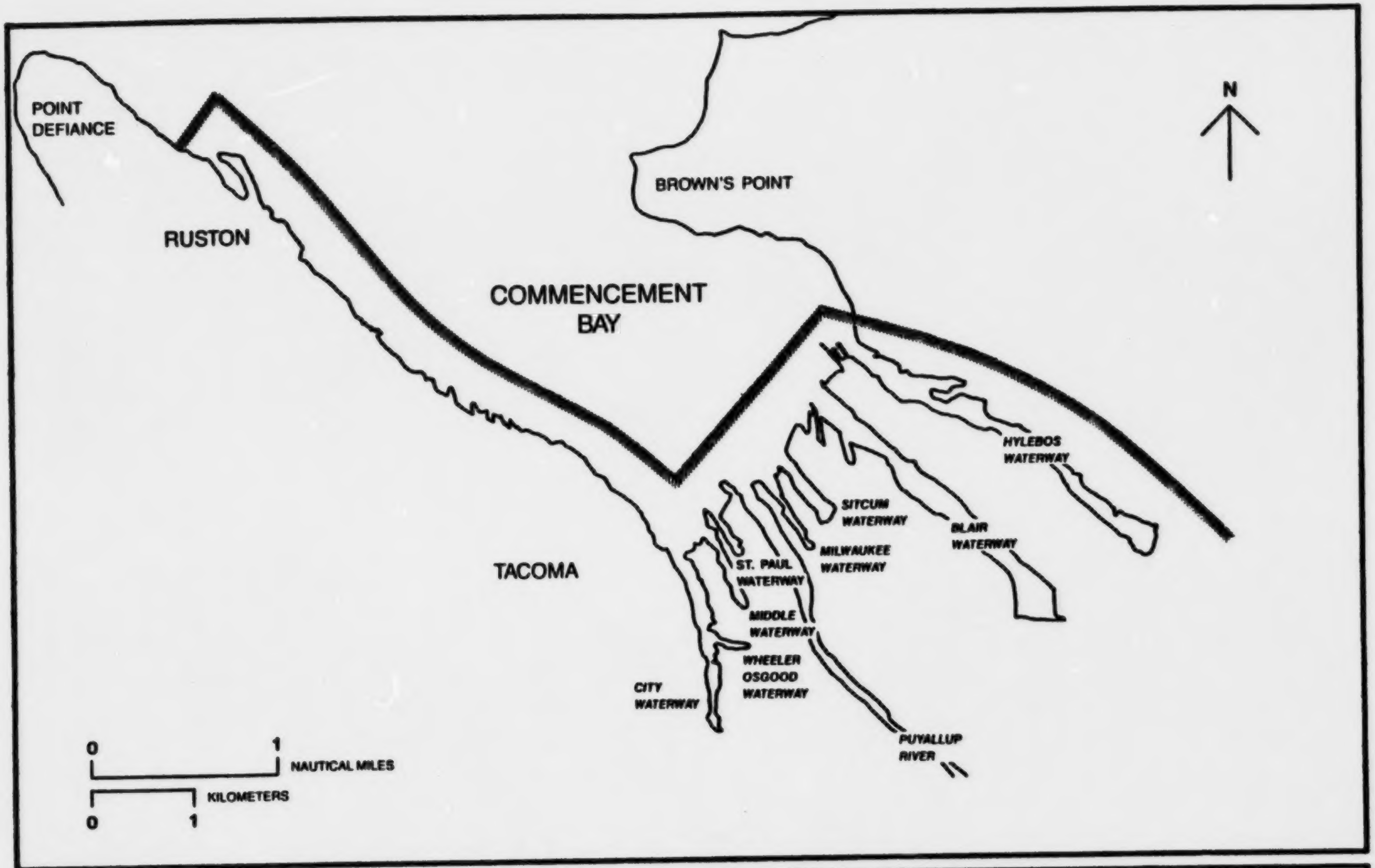

POINT DEFIANCE
RUSTON
BROWN'S POINT
COMMENCEMENT BAY
N
HYLEBOS WATERWAY
SITCUM WATERWAY
BLAIR WATERWAY
MILWAUKEE WATERWAY
ST. PAUL WATERWAY
TACOMA
MIDDLE WATERWAY
WHEELER OSGOOD WATERWAY
CITY WATERWAY
PUYALLUP RIVER
0
1
NAUTICAL MILES
KILOMETERS
0
1

Figure 1.3. Commencement Bay Nearshore/Tideflats study area.

Puyallup River; numerous storm drains, seeps, and open channels; groundwater seepage; atmospheric fallout; and spills. The Tacoma-Pierce County Health Department summarized point and nonpoint sources in 1983, identifying 334 drains (pipes), seeps, and open channels that empty into the Nearshore/Tideflats area (Rogers et al. 1983). Recent investigations by regulatory agencies have identified 429 additional point and nonpoint discharges in the study area. All known discharges were assigned an identifier with their locations and description and were compiled in the project database (Tetra Tech 1985).

Previous investigations of the nearshore waters of Commencement Bay demonstrated the existence of sediment contamination by toxic pollutants, accumulation of some of these substances by biota, and possible pollution-associated abnormalities in indigenous biota (Crecelius et al. 1975; Riley et al. 1980, 1981; Malins et al. 1980, 1982; Gahler et al. 1982). These studies indicate that the highest concentrations of certain metals (arsenic, copper, lead, mercury) were found in sediments in the waterways, along the southwest shore, and near the ASARCO smelter. Sediment contamination by persistent organic compounds (e.g., PCBs) was detected in the heavily industrialized waterways and along the Ruston-Pt. Defiance Shoreline.

The toxicity of Commencement Bay sediments to infaunal amphipods was studied using acute bioassays (Swartz et al. 1982a,b). The waterways contain both highly toxic and nontoxic sediments with heterogenous spatial distributions. Sediments with the highest toxicity were detected near docks, drains, and ditches, which are most likely associated with pollutant sources. In the waterways, higher toxicities were observed in intertidal sediments compared with those from midchannel and subtidal sites.

Commencement Bay, like much of the Puget Sound system, supports important fishery resources, especially anadromous salmonid populations. Although occupying Commencement Bay for only part of their life cycle, these species have critical estuarine migratory and rearing habitat requirements. The Commencement Bay area also supports recreational fisheries, including pollock, hake, rockfish, and cod. In addition, many of the other important fishes and invertebrates (e.g., English sole and crab) live in contact with the bottom sediments, resulting in a high potential for uptake of sediment-associated contaminants. Studies indicate that the incidence of liver lesions is greatest in fish from areas with high levels of sediment-associated contaminants (Malins et al. 1980). Higher prevalences of abnormalities have also been found in organs of shrimp and crabs from Commencement Bay waterways (Malins et al. 1980). Concern exists over the potential human health impacts from consumption of local seafood organisms that contain chemical contaminants. The Tacoma-Pierce County Health Department issued an advisory on fish consumption in 1982.

1.4 COOPERATIVE AGREEMENT

The general objective of the work planned under the U.S EPA/WDOE Cooperative Agreement is to identify the worst problems and to provide a database and framework for future activities. The ultimate goal of the Superfund project is to remedy public health or environmental threats in a prioritized manner. The Remedial Investigation focuses on sediment contamination, effects on biota, and sources of contamination. The overall scope of the Remedial Investigation includes the following tasks:

Task 1. Investigative support
Task 2. Development of preliminary remedial objectives
Task 3. Determine type and extent of contamination and exposure pathways
Task 4. Determine sources of contamination and characterize as current or historical
Task 5. Endangerment assessment support
Task 6. Identify potential remedial technologies
Task 7. Safety plan, quality assurance/quality control plan.

The key questions to be answered during the Remedial Investigation include:

- Is the area contaminated?
- Does the contamination result in adverse effects?
- Is there a potential threat to public health?
- Can the contaminant sources be identified?
- What are the potential remedial action alternatives?
- Would remedial action reduce the threat to the environment or to public health?

In order to answer these questions, the following goals and objectives were set for the Remedial Investigation:

- Define a problem sediment
- Apply definition of problem sediment in order to delineate problem areas
- Determine problem chemicals for problem areas
- Determine problem sources for problem chemicals
- Prioritize problem areas, problem chemicals, and problem sources
- Assess impacts of fish and crab consumption on human health
- Document alternative methods of dredging, handling, and disposing of contaminated sediments
- Initiate a decision-making framework for managing the disposal of contaminated sediments
- Identify potential remedial alternatives.

1.5 REPORT OVERVIEW

This report represents work completed under the U.S. EPA/WDOE Cooperative Agreement for Task 3 (determine type and extent of contamination and exposure pathways), Task 4 (determine sources of contamination and characterize as current and historical sources), and Task 5 [endangerment (public health) assessment]. The Commencement Bay Superfund Investigation includes various integrated program components, including assessments of chemical contamination, biological effects, toxicity, public health concerns, source identification, and identification of potential remedial actions and technologies. Volume 1 contains Sections 1 through 6. Volume 2 contains Sections 7 through 11. The methods and results for each individual study component are included in Sections 2 and 3, respectively, of this report. Section 4 describes quantitative relationships among contamination and biological effects that form the basis for estimating contaminant effect levels. An assessment of public health risks from consumption of contaminated seafood is included as Section 5. All of the study results described in Sections 3 through 5 are then integrated into an identification and prioritization of problem areas in Section 6. Section 7 contains source evaluations for the previously identified areas and contaminants. High priority areas with identified sources are recommended for remedial actions in Section 8. An overview of contamination and biological effects in the entire study area is presented in Section 9. A retrospsective evaluation of the study design and recommendations for future studies are presented in Section 10. References are provided in Section 11. All raw data collected as part of the present study are included in Appendices I-XV.

2.0 METHODS

2.1 GENERAL APPROACH

2.1.1 Study Design

Field studies for the Commencement Bay Nearshore/Tideflats Remedial Investigation were designed to document the degree and spatial extent of chemical contamination, adverse biological effects, and potential threats to public health. This information was used in conjunction with historical data to formulate decision criteria which, in turn, were used to identify problem areas and to prioritize these areas for possible source control and/or sediment remedial action. This decision-making approach is described in detail in Tetra Tech (1984a). That document includes rationales for the selection of chemical and biological variables and examples of the development and application of the decision criteria.

The general study design for the Commencement Bay project is presented in Table 2.1. Sediment contamination was measured in two media: bottom sediments (surface and subsurface) and water column particles. Four kinds of biological effects of chemical contamination were also measured: alteration of benthic macroinvertebrate assemblages, toxicity to bioassay organisms (amphipods and oyster larvae), prevalence of histopathological disorders in English sole livers, and bioaccumulation (English sole and cancrid crab muscle tissue, English sole livers). In addition to the data collected as part of the main Commencement Bay project, contaminant/effects information was collected in Blair Waterway as part of the Blair Waterway Dredging Survey, a combined effort between the Port of Tacoma and the Commencement Bay Superfund project. Because these samples were collected using methods identical to those of the Commencement Bay project, the resulting data were included in the analyses in the present report.

2.1.2 Station Locations

Location of stations sampled during the Commencement Bay project are presented in Figures 2.1-2.7. Locations of the Blair Waterway Dredging Survey stations are presented in Figures 2.2, 2.3, and 2.5. State plane coordinates and water depths (corrected to mean lower low water) of all stations are listed in Appendix XIV. The average water depth of stations sampled for benthic infauna in each study area is summarized in Table 2.2.

Stations selected for a preliminary survey in January, 1984 (Figures 2.2 and 2.7) were sampled primarily for sediment chemistry, and the resulting information was used for the following purposes:

- Confirmation of data from previous studies, especially in areas with little or conflicting data on sediment contamination

- Collection of sediment quality data from project areas that had not been sampled previously

TABLE 2.1. SUMMARY OF GENERAL STUDY DESIGN

	Number of Stations			
Variable	Commencement Bay	Carr Inlet	Study Areas[a] Sampled	Time of Sampling[b]
Sediment Chemistry				
Surface	15	4[c]	HY,BL,MI,MD,CI,RS,CR	January
	111	4	All	March
	12		BL	July
Subsurface	18		HY,SI,SP,MD,CI,RS	May
	17		BL	July
Water Column Chemistry	9		HY,BL,SI,MI,MD,CI	April August
Benthic Macroinvertebrates	44	4	All	March
	6		BL	July
Sediment Bioassays	46	4	All	March
	6		BL	July
Fish Histopathology	15	2	All	June
Bioaccumulation	15	2	All	June

[a] The nine study areas include Hylebos (HY), Blair (BL), Sitcum (SI), Milwaukee (MI), St. Paul (SP), Middle (MD) and City (CI) Waterways, the Ruston-Pt. Defiance Shoreline (RS), and Carr Inlet (CR).

[b] All sampling was conducted in 1984. The stations sampled in January were part of the preliminary survey and the stations sampled in July were part of the Blair Waterway Dredging Survey.

[c] At two of these stations, only conventional sediment variables were measured.

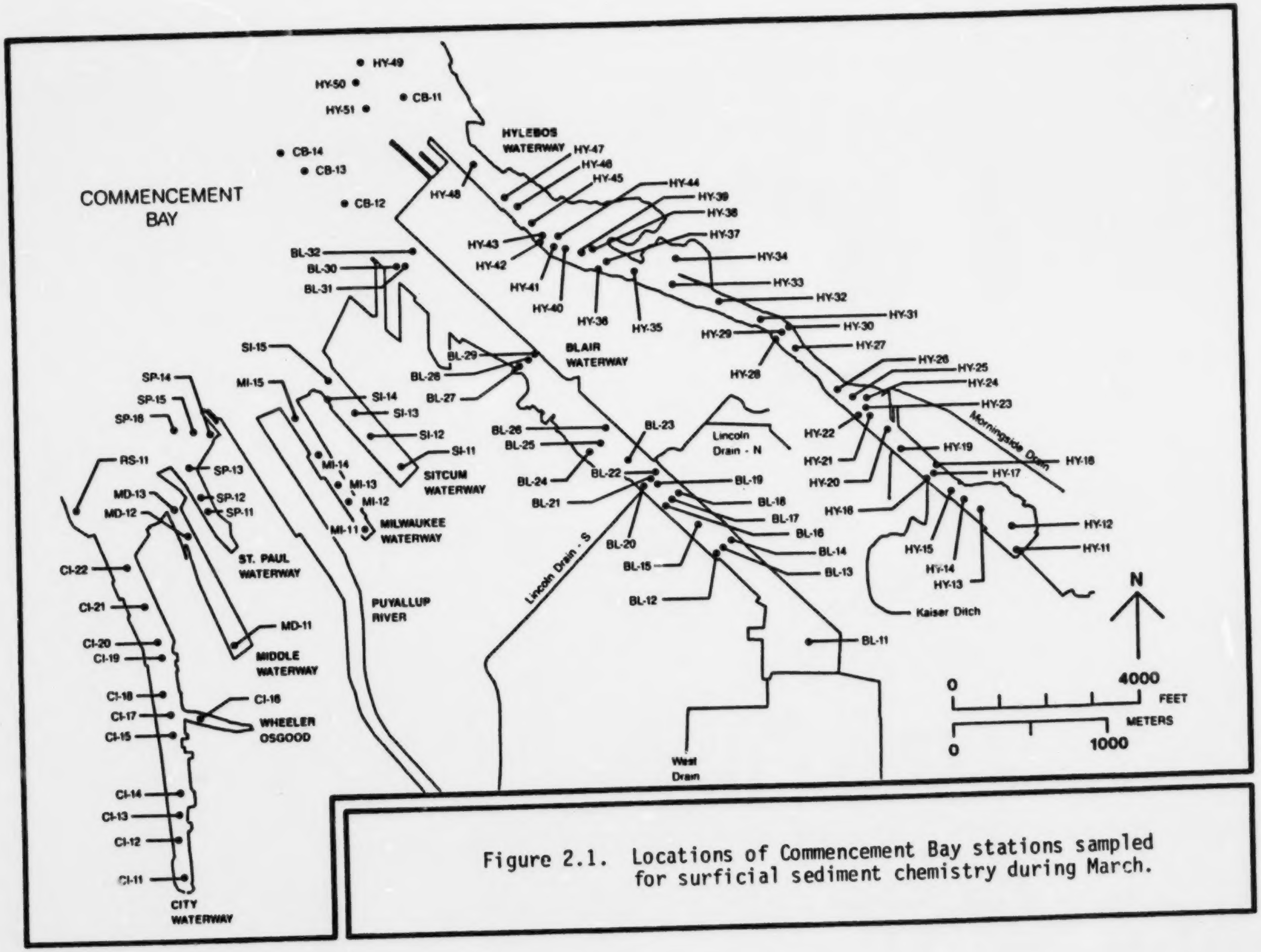

COMMENCEMENT BAY
HY-49
HY-50
HY-51
CB-11
CB-14
CB-13
CB-12
HYLEBOS WATERWAY
HY-48
HY-47
HY-46
HY-45
HY-44
HY-39
HY-38
HY-37
HY-43
HY-42
HY-41
HY-40
HY-36
HY-35
HY-34
HY-33
HY-32
HY-31
HY-30
HY-29
HY-28
HY-27
HY-26
HY-25
HY-24
HY-23
HY-22
HY-21
HY-20
HY-19
HY-18
HY-17
HY-16
HY-15
HY-14
HY-13
HY-12
HY-11
Morningside Drain
Kaiser Ditch
BL-32
BL-30
BL-31
BLAIR WATERWAY
BL-29
BL-28
BL-27
BL-26
BL-25
BL-24
BL-23
BL-22
BL-21
BL-20
BL-19
BL-18
BL-17
BL-16
BL-15
BL-14
BL-13
BL-12
BL-11
Lincoln Drain - N
Lincoln Drain - S
West Drain
SI-15
SI-14
SI-13
SI-12
SI-11
SITCUM WATERWAY
MI-15
MI-14
MI-13
MI-12
MI-11
MILWAUKEE WATERWAY
PUYALLUP RIVER
SP-14
SP-15
SP-16
SP-13
SP-12
SP-11
ST. PAUL WATERWAY
RS-11
MD-13
MD-12
MD-11
MIDDLE WATERWAY
CI-22
CI-21
CI-20
CI-19
CI-18
CI-17
CI-16
CI-15
CI-14
CI-13
CI-12
CI-11
WHEELER OSGOOD
CITY WATERWAY
N
0
4000
FEET
METERS
0
1000

Figure 2.1. Locations of Commencement Bay stations sampled for surficial sediment chemistry during March.

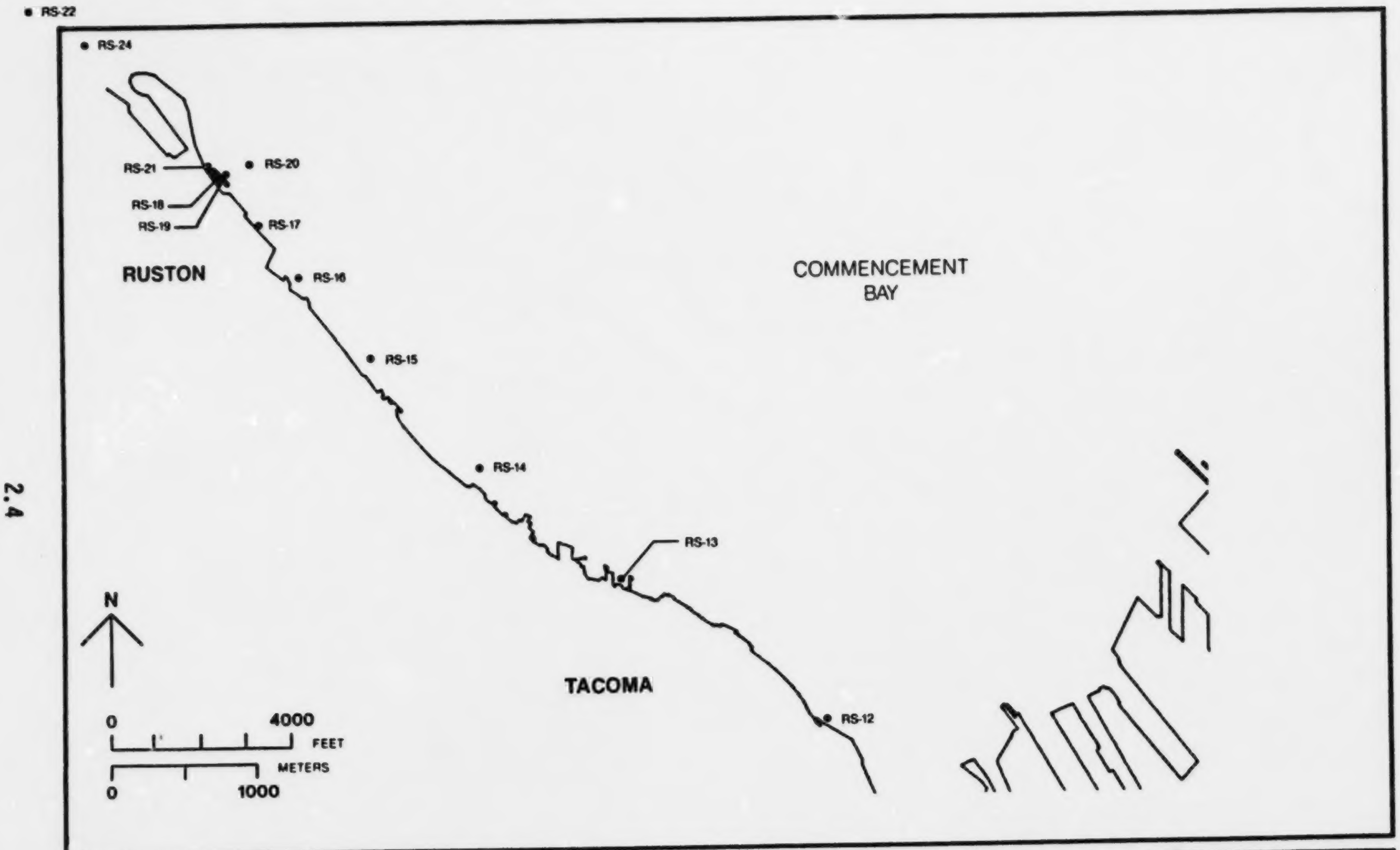

RS-22
RS-24
RS-21
RS-20
RS-18
RS-19
RS-17
RUSTON
RS-16
COMMENCEMENT
BAY
RS-15
RS-14
RS-13
N
TACOMA
0
4000
FEET
METERS
0
1000
RS-12

Figure 2.1. (Continued).

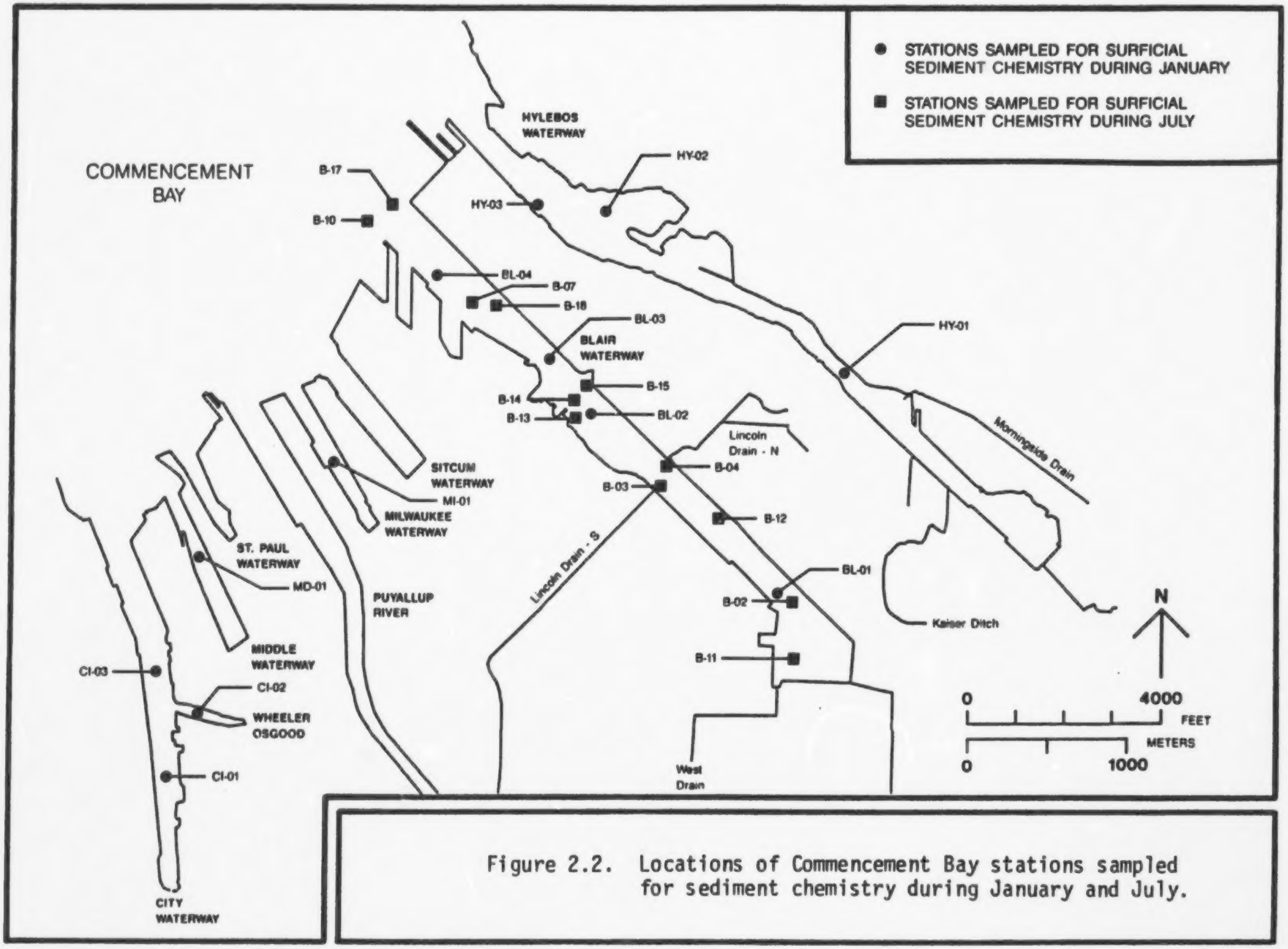

● STATIONS SAMPLED FOR SURFICIAL SEDIMENT CHEMISTRY DURING JANUARY
■ STATIONS SAMPLED FOR SURFICIAL SEDIMENT CHEMISTRY DURING JULY
COMMENCEMENT BAY
HYLEBOS WATERWAY
HY-02
HY-03
HY-01
B-17
B-10
BL-04
B-07
B-18
BL-03
BLAIR WATERWAY
B-15
B-14
B-13
BL-02
Lincoln Drain - N
B-04
B-03
B-12
BL-01
B-02
B-11
West Drain
Lincoln Drain - S
Morningside Drain
Kaiser Ditch
N
0
4000
FEET
METERS
0
1000
SITCUM WATERWAY
MI-01
MILWAUKEE WATERWAY
ST. PAUL WATERWAY
MD-01
PUYALLUP RIVER
MIDDLE WATERWAY
CI-03
CI-02
WHEELER OSGOOD
CI-01
CITY WATERWAY

Figure 2.2. Locations of Commencement Bay stations sampled for sediment chemistry during January and July.

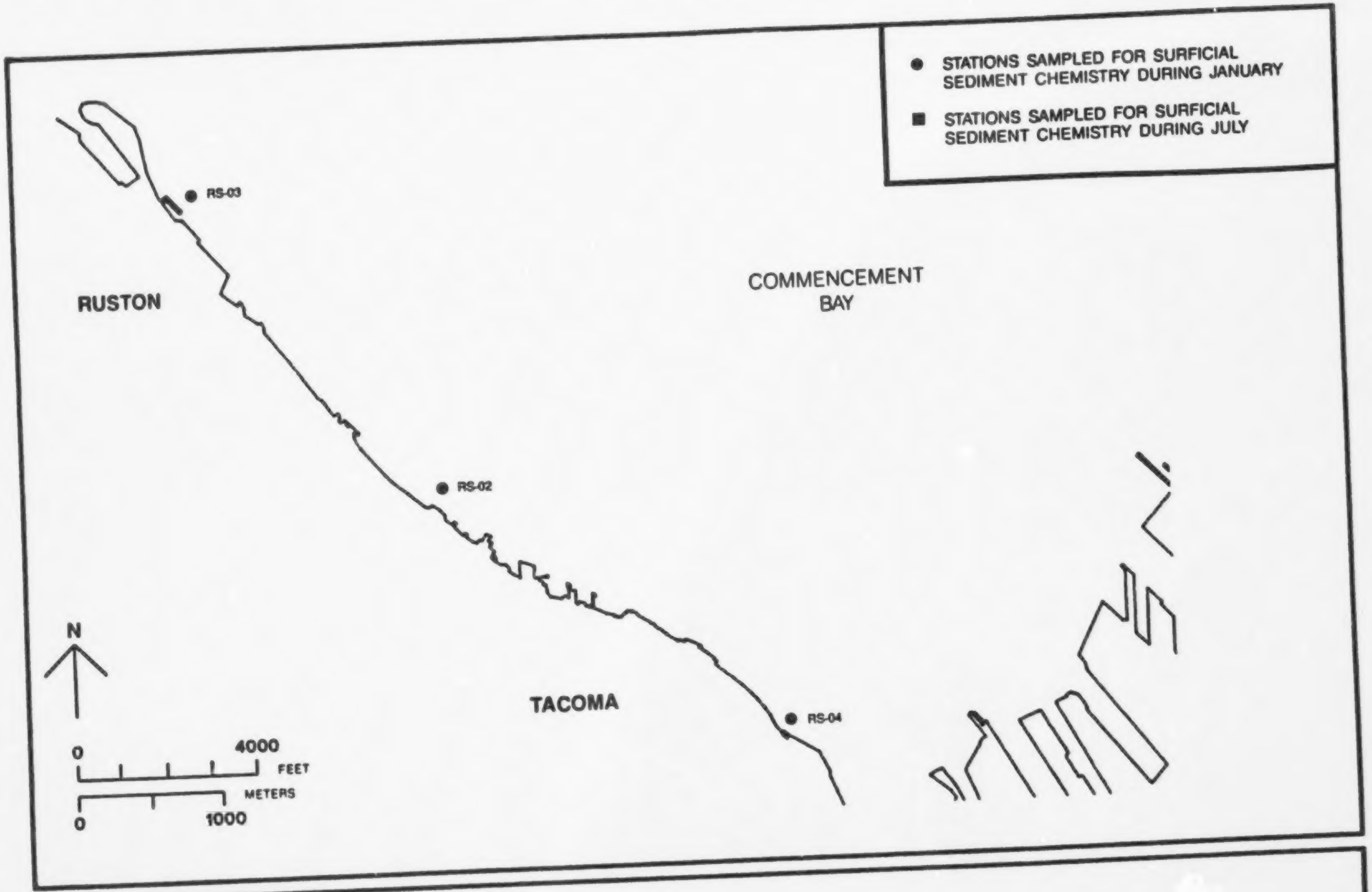

● STATIONS SAMPLED FOR SURFICIAL SEDIMENT CHEMISTRY DURING JANUARY
■ STATIONS SAMPLED FOR SURFICIAL SEDIMENT CHEMISTRY DURING JULY
RS-03
RUSTON
COMMENCEMENT BAY
RS-02
N
TACOMA
RS-04
0
4000
FEET
METERS
0
1000

Figure 2.2. (Continued).

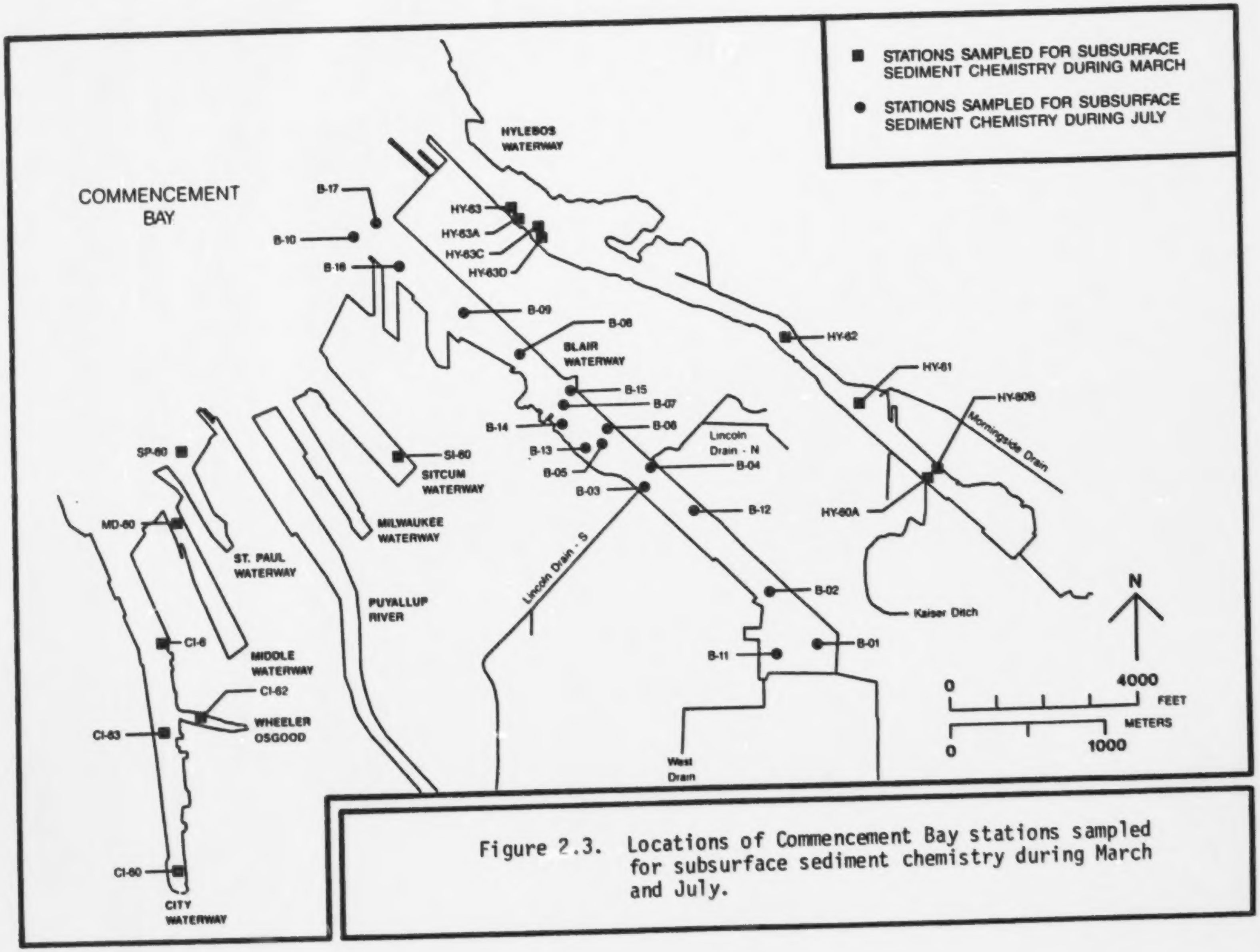
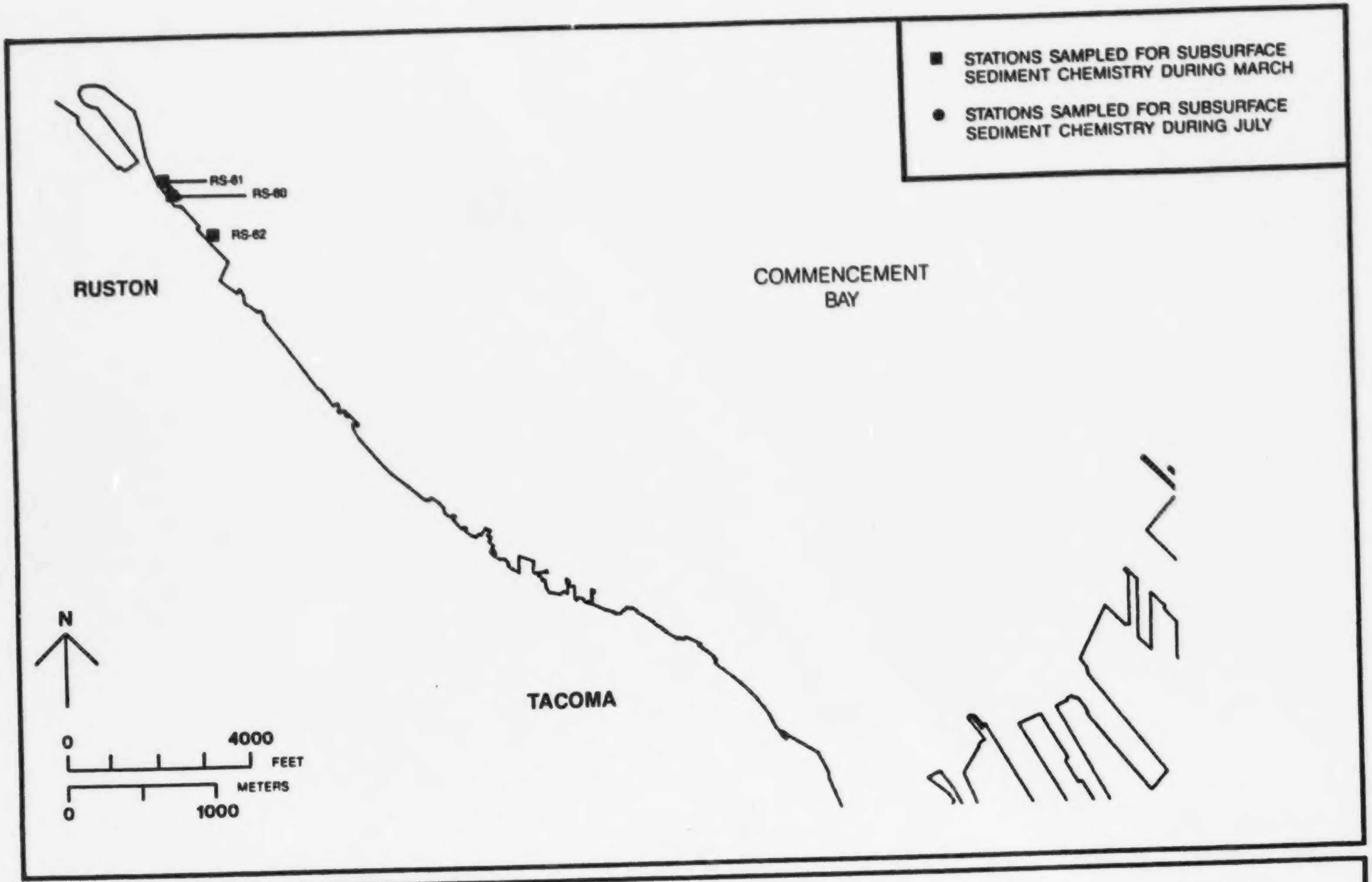

■ STATIONS SAMPLED FOR SUBSURFACE SEDIMENT CHEMISTRY DURING MARCH
● STATIONS SAMPLED FOR SUBSURFACE SEDIMENT CHEMISTRY DURING JULY
COMMENCEMENT BAY
HYLEBOS WATERWAY
B-17
B-10
B-16
HY-63
HY-63A
HY-63C
HY-63D
B-09
B-08
BLAIR WATERWAY
HY-62
HY-61
HY-60B
Morningside Drain
B-15
B-07
B-14
B-06
B-13
B-05
B-03
Lincoln Drain - N
B-04
B-12
HY-60A
SP-60
SI-60
SITCUM WATERWAY
MILWAUKEE WATERWAY
MD-60
ST. PAUL WATERWAY
PUYALLUP RIVER
Lincoln Drain - S
B-02
Kaiser Ditch
N
CI-6
MIDDLE WATERWAY
B-11
B-01
CI-62
WHEELER OSGOOD
CI-63
West Drain
0
4000
FEET
METERS
0
1000
CI-60
CITY WATERWAY

Figure 2.3. Locations of Commencement Bay stations sampled for subsurface sediment chemistry during March and July.



■ STATIONS SAMPLED FOR SUBSURFACE SEDIMENT CHEMISTRY DURING MARCH
● STATIONS SAMPLED FOR SUBSURFACE SEDIMENT CHEMISTRY DURING JULY
RS-61
RS-60
RS-62
RUSTON
COMMENCEMENT BAY
TACOMA
N
0
4000
FEET
METERS
0
1000

Figure 2.3. (Continued).

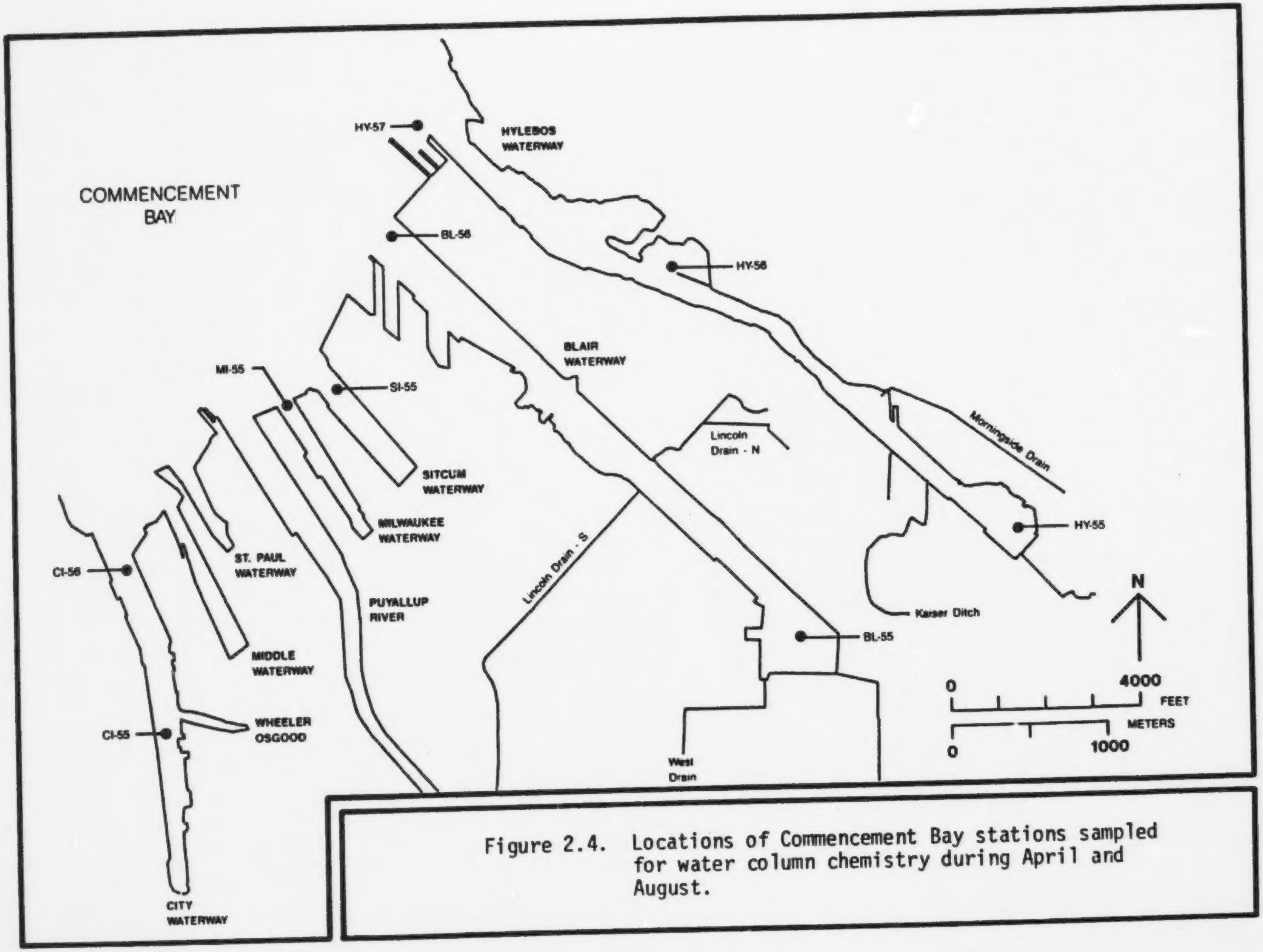

COMMENCEMENT BAY
HY-57
HYLEBOS WATERWAY
BL-58
HY-56
BLAIR WATERWAY
MI-55
SI-55
Lincoln Drain - N
Morningside Drain
SITCUM WATERWAY
MILWAUKEE WATERWAY
HY-55
Lincoln Drain - S
CI-56
ST. PAUL WATERWAY
PUYALLUP RIVER
Kaiser Ditch
N
BL-55
MIDDLE WATERWAY
0
4000
FEET
METERS
0
1000
CI-55
WHEELER OSGOOD
West Drain
CITY WATERWAY

Figure 2.4. Locations of Commencement Bay stations sampled for water column chemistry during April and August.

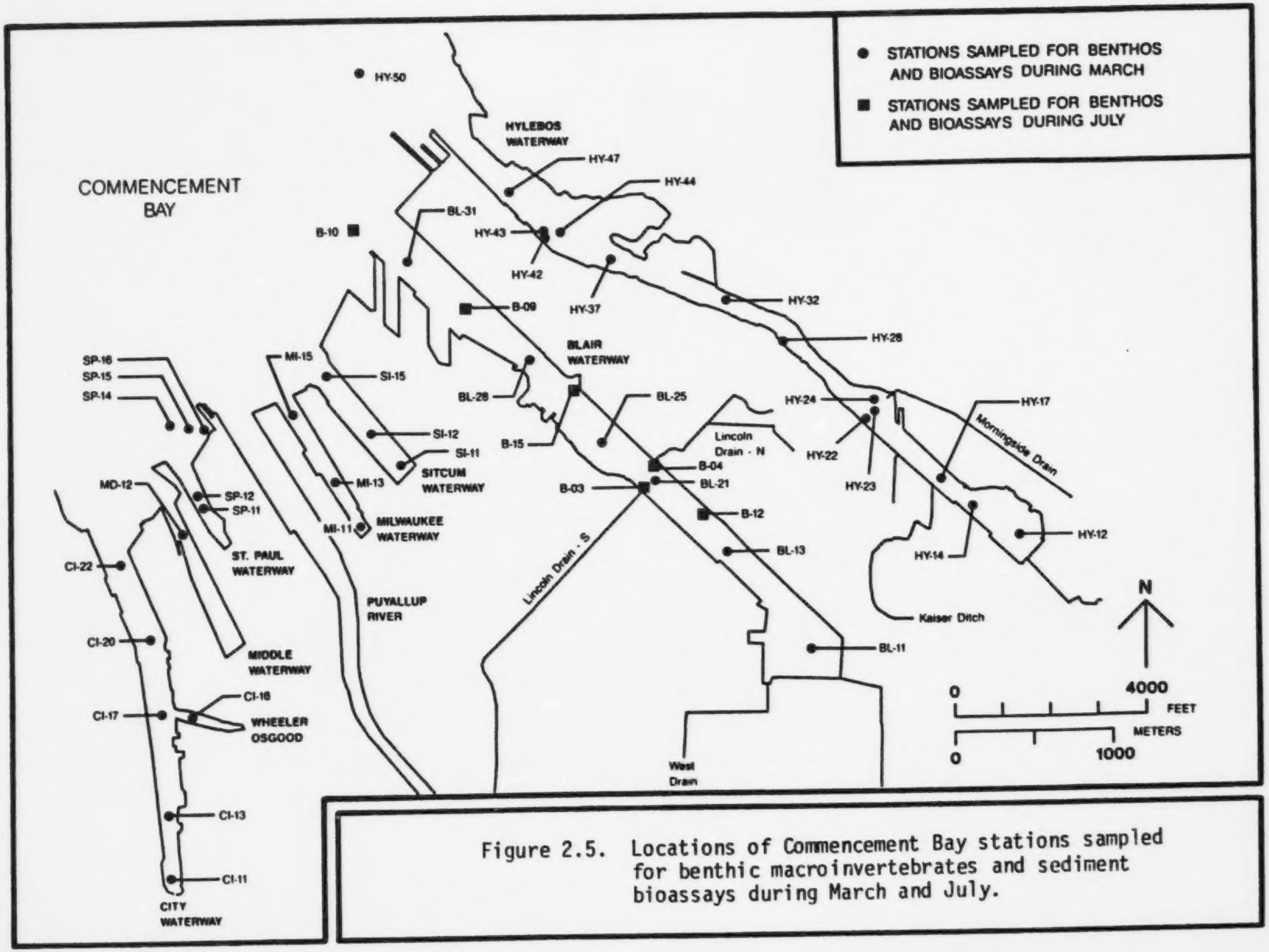

STATIONS SAMPLED FOR BENTHOS AND BIOASSAYS DURING MARCH
STATIONS SAMPLED FOR BENTHOS AND BIOASSAYS DURING JULY
COMMENCEMENT BAY
HY-50
HYLEBOS WATERWAY
HY-47
HY-44
HY-43
HY-42
HY-37
HY-32
HY-28
HY-24
HY-22
HY-23
HY-17
HY-14
HY-12
Morningside Drain
Kaiser Ditch
B-10
BL-31
B-09
BLAIR WATERWAY
BL-28
B-15
BL-25
Lincoln Drain - N
B-04
BL-21
B-03
B-12
BL-13
BL-11
Lincoln Drain - S
West Drain
MI-15
SI-15
SI-12
SI-11
SITCUM WATERWAY
MI-13
MI-11
MILWAUKEE WATERWAY
PUYALLUP RIVER
SP-16
SP-15
SP-14
SP-12
SP-11
MD-12
ST. PAUL WATERWAY
MIDDLE WATERWAY
CI-22
CI-20
CI-18
CI-17
WHEELER OSGOOD
CI-13
CI-11
CITY WATERWAY
N
0
4000
FEET
METERS
0
1000

Figure 2.5. Locations of Commencement Bay stations sampled for benthic macroinvertebrates and sediment bioassays during March and July.

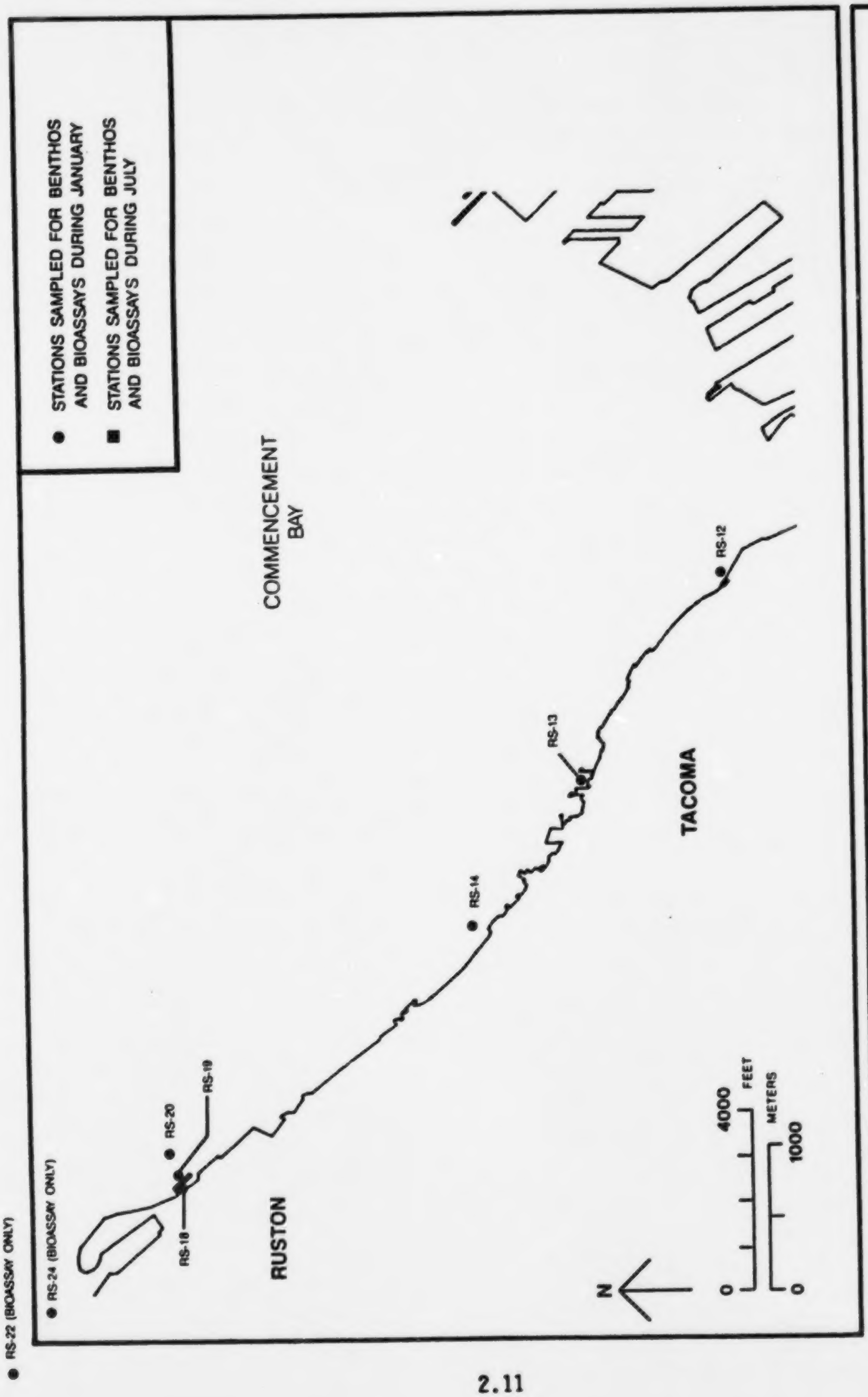

RS-22 (BIOASSAY ONLY)
RS-24 (BIOASSAY ONLY)
● STATIONS SAMPLED FOR BENTHOS AND BIOASSAYS DURING JANUARY
■ STATIONS SAMPLED FOR BENTHOS AND BIOASSAYS DURING JULY
COMMENCEMENT BAY
RS-20
RS-19
RS-18
RUSTON
RS-14
RS-13
TACOMA
RS-12
N
0
4000
FEET
0
1000
METERS

Figure 2.5. (Continued).

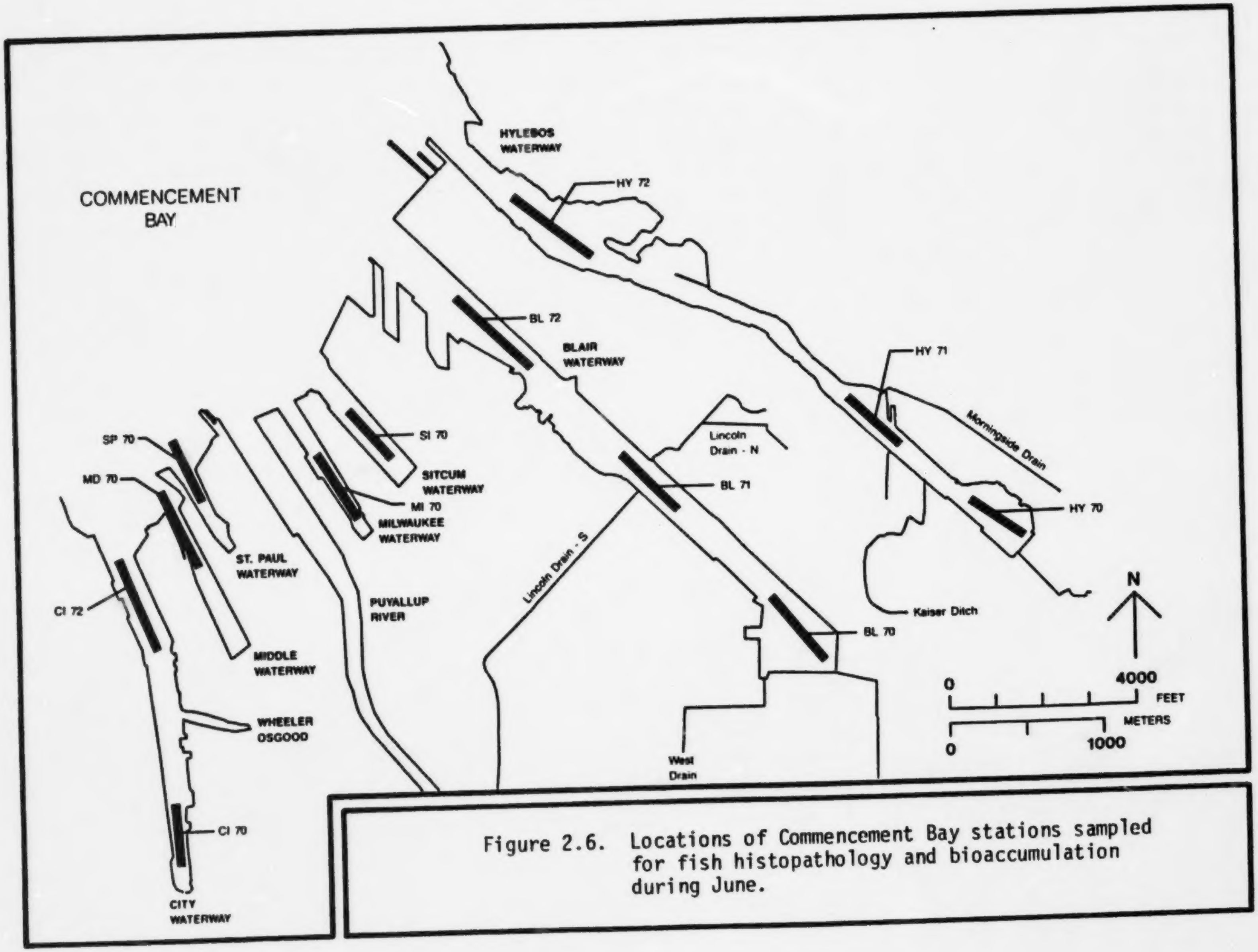

COMMENCEMENT BAY
HYLEBOS WATERWAY
HY 72
BL 72
BLAIR WATERWAY
HY 71
Morningside Drain
Lincoln Drain - N
BL 71
HY 70
SI 70
SITCUM WATERWAY
MI 70
MILWAUKEE WATERWAY
SP 70
MD 70
ST. PAUL WATERWAY
CI 72
PUYALLUP RIVER
Lincoln Drain - S
Kaiser Ditch
BL 70
N
0
4000
FEET
METERS
0
1000
MIDDLE WATERWAY
WHEELER OSGOOD
West Drain
CI 70
CITY WATERWAY

Figure 2.6. Locations of Commencement Bay stations sampled for fish histopathology and bioaccumulation during June.

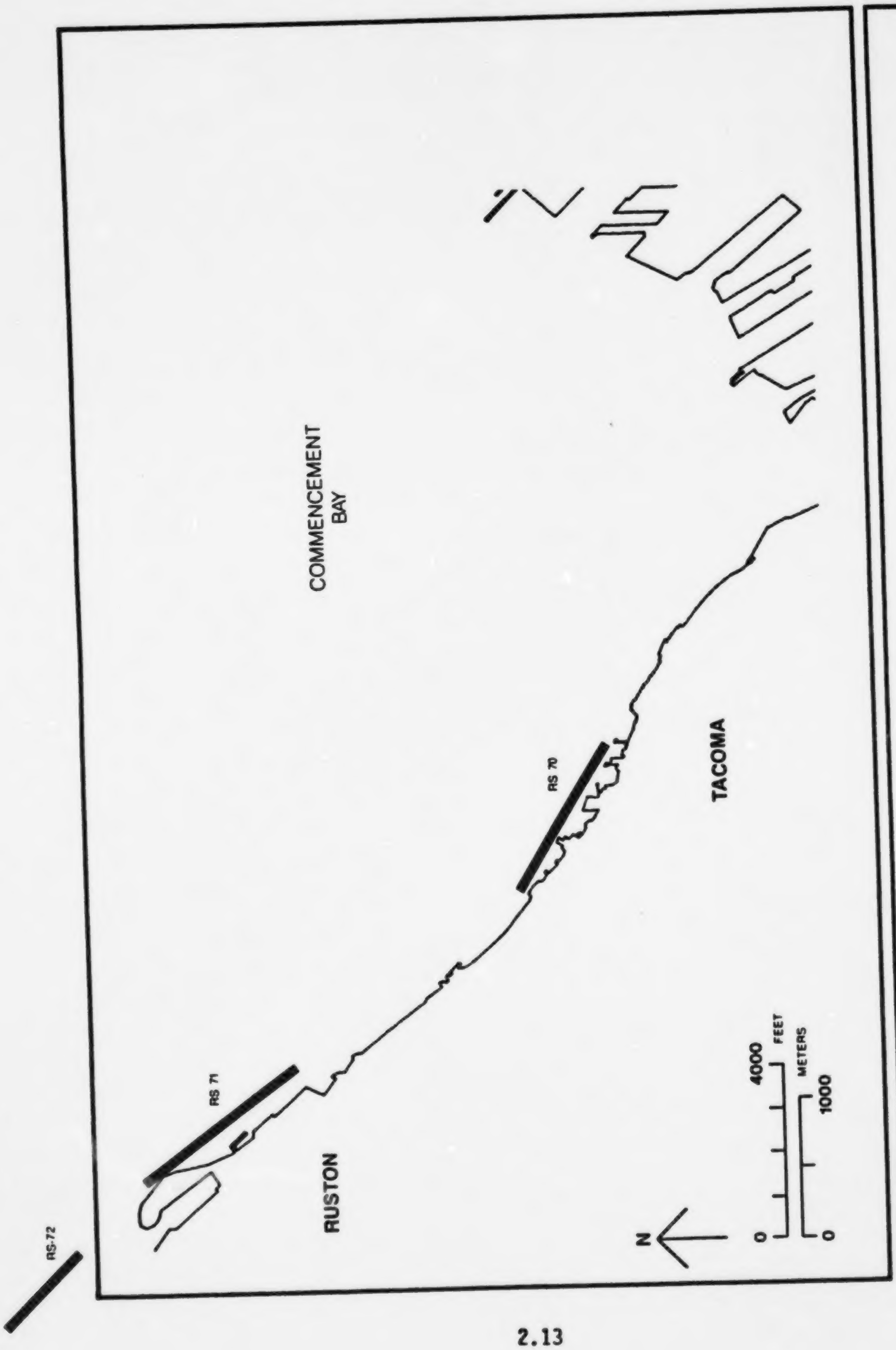
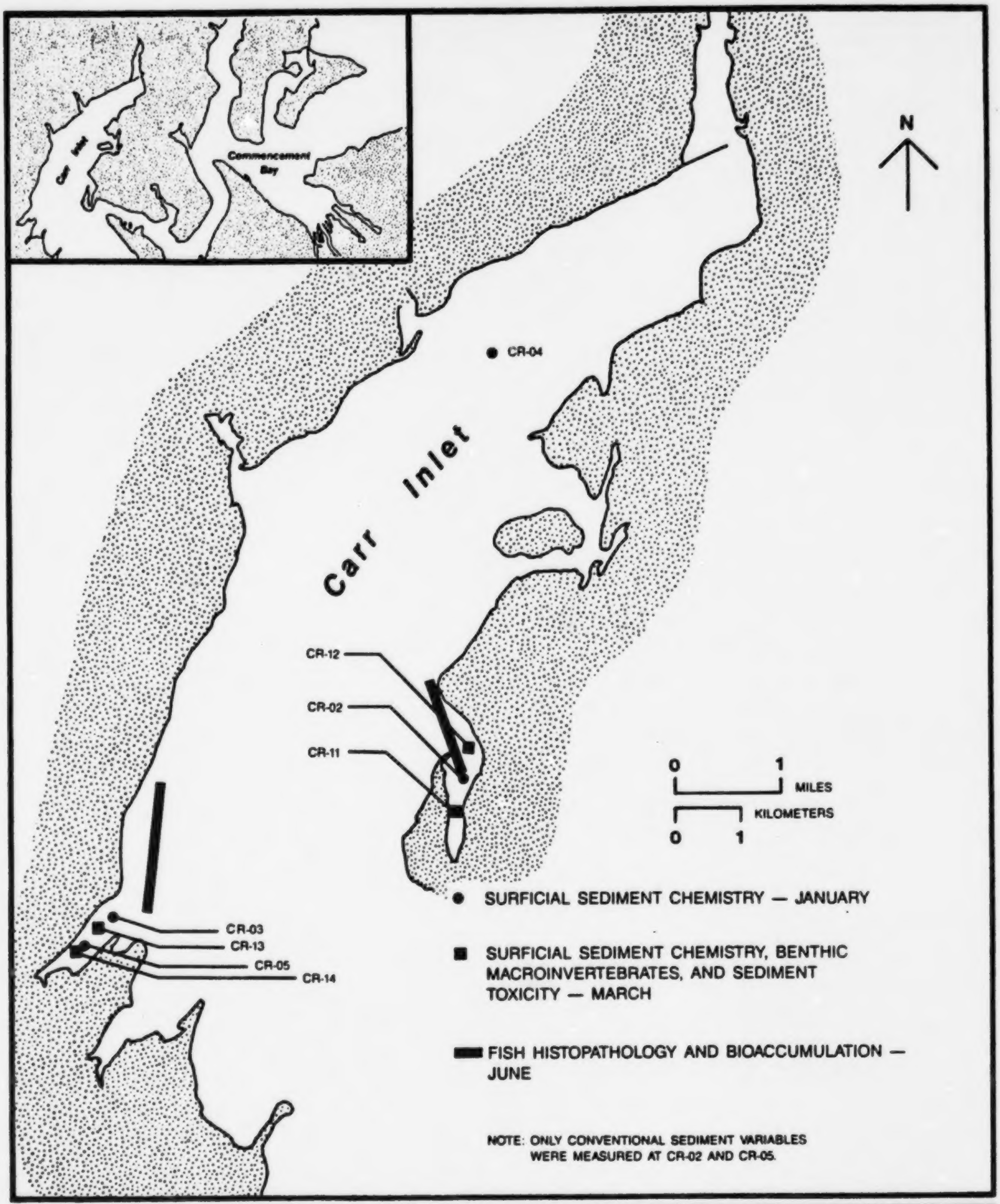

RS-72
RS 71
RS 70
COMMENCEMENT BAY
RUSTON
TACOMA
N
0
4000
FEET
0
1000
METERS

Figure 2.6. (Continued).


Carr Inlet
Commencement Bay
N
CR-04
Carr Inlet
CR-12
CR-02
CR-11
0 1 MILES
KILOMETERS 0 1
CR-03
CR-13
CR-05
CR-14
● SURFICIAL SEDIMENT CHEMISTRY — JANUARY
■ SURFICIAL SEDIMENT CHEMISTRY, BENTHIC MACROINVERTEBRATES, AND SEDIMENT TOXICITY — MARCH
▬ FISH HISTOPATHOLOGY AND BIOACCUMULATION — JUNE

NOTE: ONLY CONVENTIONAL SEDIMENT VARIABLES WERE MEASURED AT CR-02 AND CR-05.

Figure 2.7. Locations of reference stations sampled in Carr Inlet.

TABLE 2.2. MEAN WATER DEPTHS BY STUDY AREA FOR BENTHIC INFAUNA STATIONS

Study Area	Mean Lower Low Water Depth (ft)	Standard Deviation (ft)	Number of Benthic Infauna Stations
Hylebos Waterway	30.0[a]	± 3.7	12[a]
Blair Waterway	37.2	± 3.2	11
Sitcum Waterway	39.7	± 2.5	3
Milwaukee Waterway	35.2	± 2.3	3
St. Paul Waterway	12.7[b]	± 3.6	4[b]
Middle Waterway	18.0	± 0	1
City Waterway (main channel)	24.1	± 6.4	5
Wheeler-Osgood Waterway	6.1	± 0	1
Ruston-Pt. Defiance Shoreline	26.0[c]	± 5.0	6[c]
Carr Inlet	10.9	± 5.1	3[d]

[a] Excludes Station HY-44 at a depth of 5.9 ft and excludes deepwater Station HY-50 outside of Hylebos Waterway at a depth of 57.7 ft.

[b] Excludes Station SP-16 outside of waterway at 49.9 ft.

[c] Excludes Station RS-20 on transect away from the shoreline at a depth of 67.2 ft.

[d] Excludes Station CR-12 at a depth of 62.2 ft.

- Confirmation of potential reference sites and final selection of specific sampling locations
- Initial QA/QC analyses, standardization of general cruise protocols, and verification of field sampling methods
- Selection of contract laboratories and analytical protocols.

Final prioritization of areas and final selection of sampling stations for the main part of the Commencement Bay project were dependent on the elimination of data gaps through information collected in the January survey. The January survey also allowed a better definition of the spatial extent of known contaminated areas, and provided data on any "hot spots" that potentially existed in areas not sampled previously.

After a review of historical information and data from the preliminary survey, sediment stations were selected for the main part of the Commencement Bay project conducted in March, 1984. The rationales for specific station locations are presented in Tetra Tech (1984b). Briefly, stations were selected for the following purposes:

- Filling data gaps
- Defining known areas of contamination more precisely
- Determining gradients of contamination in relation to suspected sources.

Station locations were determined by line-of-site fixes on stationary shoreline features. Photographic records were made of all position alignments and ranges. These methods were tested and standardized during the preliminary survey. Loran C navigation coordinates were also recorded for each station.

2.1.3 Data Analysis Methods

2.1.3.1 Chemical Contamination--

The magnitude and spatial extent of chemical contamination of sediments was determined by comparisons of chemical concentrations among Commencement Bay study areas and with reference conditions in Carr Inlet. Known and blind replicate samples prepared from homogenized sediments were analyzed as part of the quality assurance program to establish precision of laboratory methods. Within-station variability was not evaluated. Therefore, tests for statistically significant differences between Commencement Bay and Carr Inlet that require within-station variability were not conducted. Instead, sediment contamination was defined as "significant" if the concentrations in Commencement Bay sediments exceeded all reported values (or detection limits) in any of up to nine Puget Sound reference areas, including Carr Inlet.

Conditions in the nine reference areas were reported by several investigators. Complete data for all chemicals studied in Commencement Bay were available only for the Carr Inlet reference area. As a result of a check for anomalously high values in these reference areas, a single value for phenol concentration [1,800 ug/kg dry weight (DW)] was excluded from one Carr Inlet station when the significance of Commencement Bay sediment contamination was determined. Data for 10 organic compounds in sediments from one study of Samish Inlet and Dabob Bay were also excluded because detection limits exceeded 50 ug/kg DW. These detection limits typically exceeded observed values for these compounds in other reference areas, and were substantially higher than detection limits obtained in the Commencement Bay study.

Pearson linear correlation analyses and factor analyses (varimax rotation) were performed for subsets of chemical data. Results were used to establish relationships among the distributions of chemicals in Commencement Bay study areas, and among sediment contamination, sediment toxicity, and benthic infaunal abundances. Apparent effect thresholds derived for different chemicals were established by comparing the range of concentrations for each chemical in each of three groups of stations: 1) stations where no significant toxicity was observed, 2) stations where no significant depression in benthic infaunal abundances was observed, and 3) stations where toxic or benthic effects were observed.

2.1.3.2 Biological Effects--

To determine the potential biological effects of the observed chemical contamination, each of four biological indicators (i.e., benthic macroinvertebrates, sediment bioassays, fish histopathology, and bioaccumulation) were compared between Commencement Bay and Carr Inlet. Although some comparisons were qualitative (i.e., descriptive), most were based on statistical criteria. Use of such criteria ensured that impacts were judged objectively. If possible, comparisons were made using parametric methods. Where the assumption of parametric tests could not be met using either untransformed or transformed data, nonparametric methods were used with untransformed data. For each analysis involving multiple comparisons, the Bonferroni inequality was used to achieve an experimentwise error rate of 0.05. This method tests each comparison at a significance level equal to 0.05 divided by the number of comparisons (i.e., comparisonwise error rate). By summing all comparisonwise error rates, the significance level for the entire analysis is 0.05. This method is simple but highly conservative (Snedecor and Cochran 1980). The specific statistical tests used for each biological indicator are described below.

For benthic macroinvertebrates, number of taxa and number of individuals were compared among study areas using the Kruskal-Wallis test. A posteriori multiple range comparisons were made using the Mann-Whitney U-test. A classification analysis was also conducted to group stations having similar benthic invertebrate assemblages. This analysis used the Bray-Curtis Similarity Index and the group average cluster strategy (see Boesch 1977) and was conducted on the 64 most abundant taxa. Associations between abundances of major taxa and the silt-clay content of bottom sediments were tested using the product-moment correlation coefficient. Finally, log-transformed abundances of major taxa at potentially impacted stations were compared with abundances at reference stations using either the t-test or the approximate t-test.

For sediment bioassays, values of amphipod mortality and oyster larvae abnormality were compared between potentially impacted stations and Carr Inlet stations using either the t-test or the Mann-Whitney U-test. Results of the two bioassays were compared with one another using Spearman's rank correlation coefficient.

For fish histopathlogy, effects of sex and age on prevalences of hepatic lesions were tested using a 2x2 contingency test and Spearman's rank correlation coefficient, respectively. Age-normalized prevalences of hepatic lesions were then compared between Commencement Bay areas and Carr Inlet using 2x2 contingency tests. Finally, weight-at-length values for fish having lesions were compared with values for fish not having lesions using regression analysis.

For bioaccumulation, tissue contaminant concentrations were compared among study areas using the Kruskal-Wallis test. A posteriori multiple comparisons were made using the Mann-Whitney U-test.

2.1.4 Geophysical Survey

Bottom and subbottom profiling was conducted throughout the waterways of Commencement Bay to estimate the depth of accumulated sediments. The scope of the subbottom data collection was limited to defining the soft/fluff sediment accumulation layer that overlies either the natural bottom materials exposed by dredging operations, granular fill materials placed by human activities, or waste materials dumped or discharged into the waterways. Bathymetric data were also collected to confirm the water depths recorded on existing charts and to serve as a control for the concurrently collected geophysical data.

The geophysical survey was conducted February 7-9, 1984. Horizontal control was by means of a range-azimuth system. Azimuth was determined by scaling off photo-montage maps, and range determined with a laser rangefinder (Atlas Lara 90). Profiling devices used included a Raytheon Model 719B 200 kHz transducer system with a 7.5 degree beam width and a Ross Laboratories Model 801 28 kHz transducer system with a 22 degree beam width.

Both acoustic profiling systems were "bar checked" prior to each day's survey operations to set the water velocity calibration controls and draft correction controls. The systems were also checked periodically during the course of each day's operation. Time and location marks were recorded on both recorder systems simultaneously. Data were transcribed from the acoustic system records and entered into a computer for tide reduction and final profile plotting of the data. Data were plotted with a DP-1 plotter to produce both length of waterway profiles and cross-waterway profiles. A description of the data reduction procedures and a complete set of the waterway profiles can be found in the "Commencement Bay Nearshore/Tideflats Subbottom Profiling Task Report" (Raven Systems & Research, Inc. 1984).

2.2 SEDIMENT CHEMISTRY

Most chemical analyses were performed by U.S. EPA contract laboratories following requirements under EPA IFB WA 83-A125 for trace metals and EPA

IFB 84A-266 for trace organic compounds, with adjustments and additions to the protocols specified under Special Analytical Services (SAS) contract 864-J.

2.2.1 Field Sampling

2.2.1.1 Surficial Sediment Samples--

Surficial sediments for chemical analysis and bioassays were collected using a 0.1-m^2 modified van Veen bottom grab (galvanized steel) operated in the normal manner. Because different tests were to be performed on the sediments from different stations, the number of grab samples per station varied from one to four.

Upon retrieval aboard ship, the exterior and interior of the grab were checked for hazardous vapors using an HNu ionization detector prior to any further handling. When vapors were detected (at low levels in the worst case) or when a strong odor of H_2S was present, protective breathing apparatus was worn by all personnel near the sample.

To process the sample, the grab was placed in the metal sieving stand used for the macroinvertebrates (Section 2.4). The upper flap of the grab was opened and the contents examined to ensure that sufficient penetration had been achieved and that no leakage or surface disturbance had occurred. The grab was then carefully rocked to one side without disturbing the surface layers and sufficient overlying water was decanted to expose the sediment surface on the raised side of the grab. The upper 2 cm of sediment were then removed using a glass plate as a spatula. No sediments near the sides of the grab were collected.

The material removed from the grab was placed in either a glass jar or in a large stainless steel bowl (the latter for large volumes) and carefully homogenized by stirring with a stainless steel spoon. When color or textural differences could no longer be detected, aliquots of the homogenized sediments for chemical analysis were placed in glass jars with TFE cap liners (obtained organically precleaned from the U.S. EPA sample management system), and aliquots for bioassays were placed in new polyethylene bags. All sample containers were closed, labeled, sealed with custody tape, and stored on ice until returned to shore for shipment to the laboratories.

At 20 stations in Hylebos, Blair, Sitcum, St. Paul, and City Waterways, samples were collected for analysis of volatile chemicals. At each of these stations two 10-mL vials (VOA vials from U.S. EPA) were filled with surface sediment using a stainless steel spatula to scrape surficial material into the vials. This procedure was performed prior to collecting the upper 2 cm as described above.

Prior to sampling at each station, the grab was rinsed thoroughly with site water and the glass plate, spoons, spatulas, bowl, and homogenizing jars were rinsed in sequence with site water, pesticide-grade methanol, and pesticide-grade dichloromethane, and finally wrapped or covered with aluminum foil.

2.2.1.2 Subsurface Sediment Samples--

Two coring devices were used during the subsurface sediment survey: a standard gravity corer with a 10.2-cm steel barrel in lengths of 1.5 and 3.0 m, polycarbonate core liners, and 600 lb of weight; and a box corer with a stainless steel box approximately 25 x 38 cm in cross section. Both devices were used at each sampling station to achieve maximum possible undisturbed core length. The sample handling procedures for both devices are described below.

Gravity Corer--As the corer was recovered from the water, the exterior and inside the top were checked for hazardous vapors with the vapor detector described previously. No vapor problems were ever detected at this point in the sampling.

Upon recovery, the gravity core was carefully laid nearly horizontally on the deck and the overlying water carefully decanted by tipping the cutter end of the corer slightly above horizontal. The cutter and core catcher were removed and the core liner pulled from the corer barrel. A 3.0-m wooden trough was lined with aluminum foil. The deep end of the core liner was then placed near one end of the trough and the liner was tapped gently with a rubber mallet to dislodge the sediment from the liner. As the sediment oozed out, the liner was moved along the trough to minimize distortion of the core.

After extrusion, the entire length of the core was checked for hazardous vapors. Core HY-63-G01 from off the salt pier at Occidental Chemical Corporation in Hylebos Waterway did have a significant response, and protective breathing equipment was worn while processing that core. The outside of the core was then scraped away with a stainless steel spatula and the core was measured and examined. Total core length, and the depths of color, odor, and textural horizons were recorded on field data logs. The core was also photographed. Based on these observations, sampling horizons were selected to provide adequate sample volumes and to obtain horizons representative of any major discontinuities in the core. The sediments between these horizons were then placed in a glass jar using a stainless steel spatula. Care was taken to avoid collecting material that had been in contact with the core liner or with the trough. The collected sediments were homogenized and transferred to sample jars, as was done for the surface sediments.

Between samples, the corer and core liner were washed with site water and reassembled. The spatulas, homogenizing jars, and other tools were rinsed with site water, solvent-washed, and covered with aluminum foil, as was done during the surface sediment collections.

Box Corer--As the box corer was recovered from the water, it was checked externally and internally for hazardous vapors, as before. No problems were encountered. The flaps were then held open while the water overlying the sediments was carefully removed using a small centrifugal pump. The base plate was then attached, and the box was removed and placed in a wooden rack at an angle of about 20 degrees from vertical. The side of the box was carefully lowered to expose the vertical sediment face. All samples were sufficiently cohesive that no slumpling occurred when the box was opened. Prior to further handling, the core was checked across the exposed face for the presence of hazardous vapors.

The outer layer of the core was scraped away to expose the sediment horizons. The total core depth and the depths of color and textural horizons were recorded, and the core was photographed. As with the gravity core, the horizons sampled for chemical analysis were based on these observations. At the selected depths, a 10-cm wide glass plate was inserted horizontally into the core. The overlying sediment was then cut from the box with a stainless steel spatula and lifted with the glass plate to a glass jar. The material was homogenized and aliquots prepared, as described above for surface sediment.

Between stations, the box corer was rinsed with site water, while the utensils were rinsed with water and solvent, as before.

2.2.2 Laboratory Analysis for Metals

Analyses were conducted for 16 elements, 13 of which are U.S. EPA priority pollutant metals. Three of these "metals" (i.e., antimony, arsenic, and selenium) are classified as metalloids, which are elements that do not strictly occur as metals in the environment. Following U.S. EPA convention and for ease of discussion, these three elements will be referred to as metals.

Mercury determinations for all sediments were conducted with wet sediment aliquots (0.5-g) digested using an aqua regia and $KMnO_4/K_2S_2O_8$ mixture and then analyzed by atomic absorption using the cold vapor technique (U.S. EPA Method 245.5). Analyses of the remaining 12 U.S. EPA priority pollutant metals plus barium, iron, and manganese were performed after drying the samples at 50° C and digesting a 2-g aliquot with HNO_3 and H_2O_2 according to methods detailed in the U.S. EPA Contract Lab Program IFB WA 83-A125. Digestates were taken to a range of final dilution volumes depending on sample concentrations.

In the January sediment survey, chromium, iron, manganese, and zinc were analyzed by flame atomic absorption; the remaining metals except barium were analyzed by graphite furnace with Zeeman correction. Barium was not analyzed for in the January survey. In the remaining surveys, barium, beryllium, cadmium, chromium, copper, iron, manganese, nickel, lead, and zinc were analyzed by Inductively Coupled Argon Plasma (ICAP). Silver, arsenic, antimony, selenium, and thallium were analyzed by graphite furnace with deuterium arc, background correction.

2.2.3 Laboratory Analysis for Organic Compounds

2.2.3.1 Volatile Organic Compounds --

Analyses for volatile organic compounds were conducted for 20 selected surface sediment samples and one deep core sediment sample using 2-g to 5-g (wet weight) aliquots. Just prior to purging, 10 mL of organic-free water spiked with three internal recovery standards (D_4-1,2-dichloroethane, bromofluorobenzene, and D_8-toluene) were added to the 40-mL VOA vial containing the sample. After blending, the vials were connected to a Tekmar purge and trap instrument heated in a 60° C water bath, and the samples were sparged onto traps containing 2:1 Tenax and silica.

Volatile compounds were desorbed at 180° C from the traps onto a 0.2 percent CW1500 stainless steel column (80-100 mesh, Carbopack C) held at 30° C. After desorption, the GC oven temperature was raised to 60° C and held for 2 min, and then programmed at 8° C/min to 180° C and held for 19 min. A Finnigan 3100D with a Riber SADR data system was used for GC/MS quantitation. Results were not corrected for recovery.

2.2.3.2 Semi-Volatile Organic Compounds--

Extraction and Cleanup--Prior to extraction, 100-g wet weight sediment samples were spiked with 54 isotopically labelled recovery standards that included 51 of the 56 U.S. EPA base/neutral/acid priority pollutants. Samples were spiked with a total of 5 ug/component for base/neutral compounds and 10 ug/component for acid compounds. This spike level resulted in an absolute mass of 10-20 ng/component on-column for GC/MS analyses, assuming 100 percent recovery, and represented a tradeoff between spiking with enough material to provide a reliable GC/MS signal and enabling the best determination of detection limits at low levels for undetected compounds. Separate GC/MS analyses of acid and base compound classes were not possible under the program.

Spiked sediments were Soxhlet-extracted in precleaned thimbles for 24 h using a 2:1 mixture of high-purity methylene chloride:methanol. An intercomparison with a different extraction technique (i.e., direct sediment-solvent contact under agitation) showed comparable results for most compounds. Solvents were checked to ensure that they were contaminant-free prior to use. All sediments were stirred during extraction to prevent channeling. Sediments stirred easily after most of the water was removed in the initial solvent cycles. Because of the substantial quantity of water removed from the sediment during extraction, a water fractionation step was found to be required. Water and methanol were removed from the sediment extracts by partitioning against 50 percent Na_2SO_4 saturated organic-free water, maintained at pH <2 with 6N HCl to prevent fractionation of acidic organic compounds. Following isolation of the organic fraction, the aqueous wash was adjusted to pH >12 with 6N NaOH, back-extracted with methylene chloride to recover any basic organic compounds, and discarded. The combined organic fractions were dried by passing the extract through a Na_2SO_4 column and reduced in volume to approximately 10 mL by gentle evaporation in a Kuderna-Danish (K-D) apparatus.

Elemental sulfur was removed by shaking the extracts with 0.5 mL Hg for at least 4 h. The desulfurized extracts were filtered to remove mercury and salts, reduced to approximately 3 mL under a stream of purified N_2, and subjected to gel permeation chromatography (GPC) using methylene chloride as an eluant. GPC columns (20 mm x 300 mm) were slurry-packed with 19 g of Bio Beads S-X3 (Bio Rad) that had been equilibrated for 4 h with methylene chloride, and were pressurized to 80 mm Hg (39 psi) with N_2.

Each GPC column was calibrated using a 3-mL mixture of 200 mg/mL corn oil, 4 mg/mL pentachlorophenol (PCP), and 4 mg/mL bis(2-ethylhexyl)phthalate in methylene chloride. After the calibration mixture was charged to the column, 5-mL aliquots of the eluant were collected and the amounts of PCP and phthalate were determined by gas chromatography using a flame ionization detector (GC/FID). The amount of corn oil in each 5-mL aliquot was determined gravimetrically. A plot of PCB, phthalate, and corn oil concentrations in each 5-mL aliquot was then constructed and used to determine the elution volume that maximized the removal of corn oil while minimizing the loss of phthalate and PCP. For a typical sample, the first 40 mL of eluant were discarded and the subsequent 100 mL were preserved.

Following GPC cleanup, most sediment extracts were purified further using disposable 3-mL solid phase extraction columns (SPE; Baker-10 Octadecyl). Extracts from GPC were concentrated to less than 6 mL by K-D, and then to 1 mL using N_2. A 10 percent (100 uL) aliquot was removed for PCB analysis. The remaining extract was transferred to an 8-mL test tube with 3 mL of methanol and reduced in volume to 1 mL using N_2 to remove methylene chloride. Each SPE column was conditioned with three column volumes of methanol prior to adding the extracts and eluting with 7 mL of methanol. All used SPE columns were archived. An excess of methylene chloride was then added to the eluants and the mixtures were reduced in volume by K-D to approximately 1 mL, transferred to autoinjection vials, reduced to 0.5 mL using N_2, and submitted for GC/MS analysis. All GC/MS results were corrected for losses during sample workup using the isotopically labeled recovery standards spiked to each sample.

The 10 percent aliquots (100 uL) removed for PCB analysis were diluted to 1 mL with hexane, charged to 3 g Alumina III (7 percent volume/weight) in a 5-mL disposable pipet, and eluted with 11 mL of 20 percent methylene chloride in hexane. The eluants were subsequently exchanged into isooctane, adjusted to a final volume of 1 mL by K-D, and submitted for analysis by gas chromatography/electron capture detection (GC/ECD).

Surface sediment samples from 55 of the 115 March sampling sites were processed using silica gel chromatography instead of the SPE technique. Tests using labelled recovery standards showed that equivalent recoveries were obtained for most compounds using the two techniques, but that the SPE technique enhanced recovery of phthalates and low molecular weight chlorinated compounds such as dichlorobenzenes, hexachlorobenzene, and hexachlorobutadiene. Because of this factor and the ease of analysis using SPE chromatography, the SPE technique was used with all subsequent sediment, particulate material, and tissue samples.

The 55 March surface sediment extracts processed by silica gel chromatography were subjected to acid/base partitioning after GPC cleanup in order to isolate organic acids and bases that could be lost on silica gel. Silica gel columns, topped with 2 cm of Na_2SO_4, were prepared using 11 g silica gel (EM Reagents, Kieselgel 60) that was activated at 140° C and then slurried in methylene chloride. After packing, all columns were rinsed with 40 mL of pentane prior to loading the sample extract. Four eluants were collected from the columns: (1) 22 mL pentane; (2) 44 mL of 3 percent methylene chloride in pentane; (3) 44 mL of 1 percent methanol in methylene chloride; and (4) 44 mL of 100 percent methanol. The first and last eluants, containing aliphatic hydrocarbons and polar substances (e.g., pigments), were combined and archived. The second eluant was diluted to 50 mL with hexane and a 10 percent aliquot (5 mL) was removed, concentrated to a final volume of 1 mL, and submitted for PCB analysis by GC/ECD. The remainder of the second eluant was then combined with the third eluant and the acid/base fractions, concentrated to a final volume of 0.5 mL, and submitted for GC/MS analysis.

Surface sediments from the 17 sites sampled in January were subjected to a more rigorous analysis using high pressure liquid chromatography (HPLC) to separate chemically the extracts into three neutral fractions after organic acids and bases had been isolated. Each of the five analytical fractions was analyzed by GC/MS, and the fraction containing PCBs was also analyzed by GC/ECD. The same mixture of isotopically labelled recovery-standards used in later analyses was also used in this procedure. Recovery-corrected results between this procedure and the simplified procedure used for the majority of Commencement Bay organic chemical analyses were comparable for most compounds. However, by removing sample interferences more effectively, the HPLC procedure enabled an improvement of more than an order of magnitude in detection limits (to less than 1 ug/kg dry weight). The reproducibility of results for acid and base compounds was also improved by the separate GC/MS analysis of these fractions.

GC/MS and GC/EC Procedures--Samples were analyzed using a Finnigan GC/MS with an INCOS data system. Procedures were modified from U.S. EPA 1625 procedures for the isotope dilution technique (method of standard additions) using mass spectroscopy. The major change in the 1625 procedure was that compounds for which there was no isotope analog were quantitated by using the response factor of the nearest eluting, most chemically similar labelled recovery standard. For example, benzo(g,h,i)perylene was used for the quantitation of indeno(c,d)pyrene. When a chemically similar recovery standard was not available (e.g., for tentatively identified compounds), the response factor for the d_{10}-phenanthrene was used.

2.2.3.3 Total Extractable Organic Material--

The weight of solvent-extractable organic material was determined for most sediments by determining the weight of the solvent-extracted residue obtained from a 10-g (wet weight) sediment subsample shaken for 1 h with 1:1 methylene chloride:acetone. The resulting extract was filtered, reduced in volume to approximately 5 mL by K-D, evaporated to dryness on a pre-weighed aluminum dish, and weighed. The weight of any elemental sulfur co-extracted with the organic matter was included in this determination.

2.2.4 Ancillary Analyses

2.2.4.1 Bulk Sediment Chemical Analyses--

Determinations of total organic carbon (TOC) and nitrogen (N) were made for all sediments by combustion using either a Carlo Erba Elemental Analyzer (January survey only) or a Perkin Elmer Elemental Analyzer. In the January survey, total organic carbon was measured as the difference between the total carbon content determined in combusted nonacidified sediments and total carbonate determined separately by coulometric titration. Aliquots of all subsequent samples were acidified to remove carbonate and organic carbon was determined directly.

Total solids, total volatile solids (TVS), and oil and grease determinations were made for all sediments according to procedures described by

Plumb (1981). For percent solids, an approximate 25-g aliquot of well-mixed wet sediment was transferred to a tared evaporating dish, weighed to the nearest 10 mg, and dried overnight at 103-105° C. The dried sample was cooled, desiccated, and weighed to constant weight. The percent solids was calculated based on the residue weight divided by the original sediment wet weight.

TVS determinations were made by weighing the residue from the total solids analysis after ignition at 550 ±50° C in a muffle furnace for a minimum of 1 h. Volatile solids content was calculated based on the difference between total solids residue and the volatile solids residue weights divided by the total solids residue weight.

Oil and grease determinations were conducted with 10-g to 20-g aliquots of wet sediment acidified with sulfuric acid to pH 2. $MgSO_4 \cdot H_2O$ was added to the acidified sample to make a uniform paste. After solidification, the sample was ground, added to a paper extraction thimble, and extracted with Freon in a Soxhlet apparatus for 4 h. The resulting extract was distilled using a water bath at 70° C, and the residue weight after removal of Freon was recorded as total oil and grease content.

Sulfide was determined by titrating SAOB-buffered sediment samples (20-g aliquot) with a standardized lead perchlorate solution and measuring the endpoint with a specific ion electrode. Samples collected during the January survey were immediately preserved in SAOB buffer upon receipt at the laboratory, but subsequent samples analyzed by a different laboratory were not buffered until analysis. Because holding times sometimes exceeded 30 days for these latter samples, total sulfide measurements were qualified under QA review as minimum estimates. Sulfide levels in the January survey samples showed a greater range in concentration than did the later samples.

2.2.4.2 Grain Size Analysis--

Sediment grain size was determined by sieve and pipet analysis. After dry and wet sieving of the gravel and sand fractions (-1 to 4 phi), the remaining silt/clay fraction was treated with H_2O_2 to remove organic material, suspended in a settling column with a deflocculating agent, and sampled over time according to procedures detailed by Folk (1974). The percent weights of the gravel, sand, and silt fractions (-1 to 8 phi) were measured for each 0.5-phi size interval. Percent weights for the clay fraction were determined to the nearest 1.0 phi. Pipet sampling was discontinued when the cumulative weight of the preceding phi size classes exceeded 95 percent of the total sample weight.

2.3 WATER COLUMN CHEMISTRY

2.3.1 Field Sampling

2.3.1.1 Metals--

In separate casts made at the stations and depths selected for organic samples, samples for the analysis of particulate metals were collected in standard 5-L PVC Scott Richards bottles. Upon retrieval aboard ship, aliquots were collected from each bottle for salinity and oxygen using standard procedures. Then 1-gal polyethylene cubitainers were carefully rinsed with the sample, filled, capped, and stored on ice until returned to the laboratory. These samples were filtered through preweighed 0.4-um Nuclepore filters, folded to protect the filtered material, and placed in polycarbonate petri dishes. The dishes were sealed, labeled, and frozen until shipped to the laboratory for reweighing and measurement of the trace metals.

2.3.1.2 Organic Compounds--

Samples for the measurement of organic compounds in suspended particulates were collected in 23-L stainless steel water bottles deployed at each of two depths at each station: near the surface (0.5 m) and at 5 m. The depths were selected to sample the brackish surface layer and the more saline, deeper water. The adequacy of these depths was determined at the start of each cruise by determining the depths of the thermocline and the halocline with probes.

The sample bottles entered and exited the water with all ports closed. The ports were opened only while sampling at the desired depth. Once sample bottles were retrieved, two separate aliquots of 125-500 mL were collected from each bottle and composited in polyethylene cubitainers. The remaining water in the sample bottles was forced by nitrogen overpressure through 147-mm glass fiber filters held in either stainless steel or aged PVC filter holders. (The filters were prepared by combustion at 500° C for 8 h followed by solvent rinsing.) This sampling procedure was repeated with multiple bottle casts until sufficient sample had been collected. In some cases samples retrieved with the steel sampler were transferred to an aged PVC pressure chamber for filtration.

While a minimum of 100 L was intended to be filtered for each sample, the filters often clogged before this quantity could be forced through. At different stations and depths, therefore, from two to eight sample bottles were filtered and from one to four filters were used. When the entire contents of a bottle could not be filtered, the volume of the remaining water was measured and the volume filtered determined by difference.

After filtration, the glass fiber filters were removed from the filter chambers with forceps, folded to protect the filtered material, and placed in glass jars with TFE cap liners. The jars were labeled, sealed with custody tape, and stored on ice until shipped to the laboratory for analysis.

The cubitainers of composited water were stored on ice until taken to the laboratory for filtration. One of the duplicate aliquots from each sample was filtered through a 0.45-um, preweighed Nuclepore filter, dried, and reweighed for the determination of the dry mass concentration of the sample. The other aliquot was filtered through a 0.4-um, combusted, silver filter for determination of carbon and nitrogen content of the particulate matter.

2.3.2 Laboratory Analysis

2.3.2.1 Metals--

Polycarbonate filters (Nuclepore; 0.45-um pore size; 142-mm diameter), were used for metal particulate filtration. After filtration, the filters were dried at 60° C and weighed for total sample weight. The entire filter was then placed in a beaker and the particulates were digested using HNO_3/H_2O_2 as for the sediments. The digestate was reduced to approximately 3 mL, filtered, and then diluted to 10 mL. The standards used to calibrate the April analyses were prepared using standard acid concentrations of 0.5 percent HNO_3. The standards used subsequently for the August survey were matrix-matched in the same acid concentrations as the sample (approximately 20 percent HNO_3).

Because of the limited sample size, mercury analysis was omitted. Analyses for barium, beryllium, cadmium, chromium, copper, iron, manganese, nickel, lead, and zinc were performed by ICAP. Silver, arsenic, antimony, selenium, and thallium were analyzed by graphite furnace atomic absorption with deuterium arc background correction. If not detected by ICAP, cadmium and lead were also analyzed by graphite furnace.

2.3.2.2 Semi-Volatile Organic Compounds--

Glass fiber filters containing particulate material were cut up into Soxhlet thimbles using solvent-rinsed scissors and spiked with isotope recovery standards at a level of 5 ug/component/sample. Procedural steps for filters were identical to those for sediments taken through the SPE chromatography protocol, except that the elemental sulfur removal and GPC (Bio Beads) cleanup steps were omitted because the extracts were not complex. The final dilution volume for the August particulate samples was reduced to 0.05 mL from the 0.5 mL used for April particulate samples in order to improve detection limits. The spike level was also lowered.

2.3.2.3 Ancillary Analyses--

The total organic carbon and nitrogen contents of particulate material were based on 0.3-L to 1-L aliquots of site water filtered through 0.45-um silver filters precombusted at 550° C for 3 h. The sample aliquots were taken from water collected for analyses of organic compounds. Organic carbon and nitrogen measurements were made on the pelletized silver filters using a Carlo Erba Elemental Analyzer. A set of standards and blank filters was analyzed with each batch of samples in order to generate a multi-point calibration curve. The calibration curves were used to determine appropriate response factors for the range of concentrations observed in each sample set (Hedges and Stern 1984).

A test was conducted to determine the amount, if any, of inorganic carbon in the particulate material. Two filters from a group of replicates were each cut approximately in half. One half was exposed to acid vapors (Hedges and Stern 1984) and the other half was untreated. Based on the lack of variation in atomic carbon-to-nitrogen ratios for the treated and untreated samples, it was concluded that organic carbon was not present in appreciable levels to warrant acid treatment of the samples.

Suspended solids concentrations were determined for each water sample collected for organic compound analyses by filtering a 1-L aliquot through 43-mm Nuclepore filters (0.45-um pore size). The wet filters were rinsed with distilled water to remove salts and dried to constant weight. Suspended solid loads determined from these filters were used to estimate the total particulate material on silver filters used in carbon and nitrogen determinations, and on glass fiber filters used for organic compound analyses. The dry weight of particulate material on Nuclepore filters analyzed for metals was determined directly.

2.4 BENTHIC MACROINVERTEBRATES

2.4.1 Field Sampling

Sediment samples analyzed for benthic macroinvertebrates were collected using a 0.06-m^2 modified van Veen bottom grab. Four replicate samples were collected at each of 54 stations. Forty-eight of these stations were occupied in March, 1984 as part of the Superfund project. The remaining six stations (all in Blair Waterway) were sampled in August, 1984 as part of the Blair Waterway Dredging Study. Samples were sieved using mesh sizes of 1.0 and 0.5 mm. All 1.0-mm fractions were analyzed taxonomically, whereas all 0.5-mm fractions were stored for possible analysis in the future.

Upon retrieval, the grab was placed on a metal sieving stand for observation of sediment characteristics. The following characteristics were recorded for each sample: sediment texture; sediment color; presence, type, and strength of odors; penetration depth; degree of leakage or surface disturbance; and presence of large animals or debris.

Samples displaying excessive leakage or surface disturbance were rejected. Samples were also rejected if they did not meet the following minimum penetration depths:

- Coarse sand and gravel - 4 cm
- Coarse to medium sand - 5 cm
- Fine sand - 7 cm
- Silt with sand or clay - 10 cm.

Once sediment characteristics were recorded, the jaws of the sampler were opened and the sediment was released into the top section of the sieving stand. It was then gently sprayed with seawater as the larger masses of sediment were broken apart. This material was rinsed into one of two stacked screen boxes (1.0- and 5.0-mm mesh) in the lower level of the sieving stand, where it was completely washed until materials no longer passed through the screens. Material retained by each screen was transferred to thick plastic bags labeled with external and internal tags. A 15 percent solution of formalin buffered with sodium borate in seawater was used in the field to fix the tissues of organisms.

2.4.2 Laboratory Analysis

All 1.0-mm benthic samples were analyzed within 2-14 days following collection. Each sample was transferred to a screening device with mesh openings slightly smaller than those originally used in the field, and the formalin was washed away using fresh water. The screened material was transferred to a clean sample container having internal and external labels, and the container was then filled with 70 percent ethanol solution. Each sample was cataloged in a rescreening log, which was later compared against field inventory notes to ensure that all samples were accounted for. As mentioned earlier, all 0.5-mm benthic samples were archived for possible analysis in the future.

Samples were sorted in one of two ways. Samples containing large quantities of coarse material were processed using a flotation technique, where the sediment was first rinsed in fresh water in a large, flat tray. The organisms that became suspended in the water (soft-bodied organisms and arthropods) were carefully poured into a sieve. This material was sorted while viewing it through a binocular dissecting microscope at a minimum of 10x power. The remaining portion of denser material was sorted using a 5x hand lens. Organisms remaining in this portion generally consisted of molluscs and some tube-dwelling or encrusting organisms associated with the sediment grains. Samples containing less dense material were not processed using the flotation technique, but were simply sorted under 10x magnification using a binocular dissecting microscope.

Organisms were first sorted into major taxonomic groups: Annelida, Arthropoda, Mollusca, Echinodermata, and other phyla. Quality control of this sorting process was performed by resorting 20 percent of each sample. Identification and enumeration of sorted organisms was to the lowest taxonomic unit possible, generally to species level. This was accomplished using dissecting and compound microscopes, the laboratory's taxonomic library, and the laboratory's reference collection. Assurance of consistent identifications among individuals within the laboratory was accomplished by continuous interaction of individuals, use of the reference collection, and use of specially designed in-house taxonomic keys for difficult genera and species.

2.5 SEDIMENT BIOASSAYS

2.5.1 Field Sampling

Field collection methods for sediment bioassays are described in Section 2.2.1.1.

2.5.2 Laboratory Analysis

2.5.2.1 Amphipod Bioassays--

The infaunal amphipod *Rhepoxynius abronius* was collected subtidally from West Beach on Whidbey Island (Washington) using a bottom dredge. Amphipods were maintained and transported in clean coolers with ice, and were returned to the laboratory within 18 h of collection.

Following their arrival in the laboratory, amphipods were kept in holding containers filled with fresh seawater (28 ppt salinity) and clean sediment and maintained at 15±1° C under continuous light until used in testing. Cultures were aerated but not fed during acclimation and were held for 4-14 days. Prior to testing, amphipods were sorted by hand from sediments and identifications were confirmed using a Wild M5 dissecting microscope. Damaged, dead, or unhealthy individuals were discarded.

Acute lethality of whole, fresh (unfrozen) sediments was measured using the methodology of Swartz et al. (1982a, 1985), which involved a 10-day exposure to test sediments. A 2-cm layer of test sediment was placed in 1-L glass jars and covered with 800 mL of clean seawater (28 ppt salinity). Each beaker was seeded with 20 amphipods and aerated. Six replicates (20 amphipods each) were run per test sediment. Five beakers served to determine toxicity, while the sixth beaker served as a reference for daily measurement of water chemistry (i.e., pH, dissolved oxygen, salinity, and temperature). Testing was conducted at 15±1° C under constant light. Test containers were checked daily to establish early trends in mortality and sediment avoidance, and also to gently sink any amphipods that had left the surface overnight and become trapped by surface tension at the air/water interface. A negative (clean) control sediment (from the amphipod collection site) was run concurrently with each series of test sediments. In addition, clean sediment spiked with $CdCl_2$ to produce a concentration of 10 mg/L was used as a positive control to ensure that response criteria (lethality) were operative.

Amphipod dilution bioassays were conducted on samples from six stations that were found to be highly toxic in initial tests. Dilution concentrations were 100, 75, 50, 25, and 10 percent test sediment. Where insufficient sediment was available for complete testing, replication was reduced and/or the higher test sediment concentrations (100 and 75 percent) were eliminated. Sediment dilutions were determined gravimetrically using a 2-cm layer of 100 percent test sediment as a standard upon which to base the remaining concentrations of that sample. Sand from West Beach on Whidbey Island was mixed with the test sediment to attain homogeneous sediment dilution weight equivalent to that of the 100 percent sample.

Bioassay tests were terminated after 10 days, when sediments were sieved (0.5-mm screen), and live and dead amphipods were removed and counted. Amphipods were considered dead when there was no response to physical stimulation and microscopic examination revealed no evidence of pleopod or other movement. Missing amphipods were assumed to have died and decomposed prior to the termination of the bioassay (Swartz et al. 1982, 1985).

2.5.2.2. Oyster Larvae Bioassays--

Adult Pacific oysters (*Crassostrea gigas*, age 3-5 yr) were obtained from Baynes Sound Oyster, a commercial oyster farm located in Union Bay, British Columbia. Prior to testing, the oysters were cleaned of fouling organisms and placed in continuous-flow conditioning trays to permit gonadal maturation. The oysters were thermally conditioned (19±1° C) for 4-6 wk in unfiltered seawater, with individual oysters periodically sacrificed to determine the state of gonadal development.

Spawning was induced by thermal stimulation and the addition of a prepared sperm suspension from a sacrificed male oyster, following standard procedures described in Chapman et al. (1983, 1984), Chapman and Morgan (1983), and ASTM (1983). The fertilized eggs were washed through a Nitex screen (0.25-mm mesh size) to remove excess gonadal tissue and were then suspended in 4 L of filtered (0.45 um nominal pore size), UV-treated seawater at incubating temperature. When microscopic examination revealed the formation of polar bodies, egg density was determined from triplicate counts of the number of eggs in 1-mL samples of a 1:99 dilution of homogeneous egg suspension.

Sediment bioassays were conducted in clean (rinsed with 5 percent nitric acid) 1-L plastic bottles. Fifteen grams (wet weight) of the appropriate sediment was added to each bottle and the volume brought up to 750 mL with treated seawater to make a final concentration in all test containers of 20 g (wet weight) of sediment per L of seawater. Two seawater and two sediment controls contained 20 g/L of clean sediment, collected from off West Beach, Whidbey Island. One seawater and one sediment control were spiked with $CdCl_2$ to produce a concentration of 10 mg/L and served as positive controls for 100 percent lethality [Martin et al. (1981) reported a 48-h EC50 of 0.61 mg/L Cd for Pacific oyster larvae]. All test sediments were run in duplicate and the controls were replicated five times.

Dilution bioassays were conducted on samples from five stations that were found to be highly toxic in initial tests. Concentrations of test sediments used in the dilution bioassays were 20, 15, 10, 5, and 2 g/L, with the remaining volume (to make up a 20-g/L concentration) provided by clean control sediment. Seawater and clean sediment controls were prepared and run in duplicate.

The sediments were suspended by vigorous shaking for 5 sec. Embryos were then added and the suspended sediments were allowed to settle. No additional agitation was provided after inoculation.

Within 2 h of fertilization, each container was inoculated with approximately 22,000 developing oyster embryos, to give an approximate concentration of 30 per mL. The containers were covered and air-incubated for 48 h at $20\pm1^{\circ}$ C. After 48 h, larvae were concentrated using a 0.038-mm sieve, quantitatively transferred to screw-cap glass vials, and preserved with 5 percent buffered formalin. Preserved samples were examined in Sedgewick-Rafter cells under 100x magnification. Because bivalve larvae sink after preservation (ASTM 1983), it was possible to discard most of the water (70 percent) from the sample vials before examining the residual volume containing the larvae.

Normal and abnormal larvae were enumerated to determine percent survival and percent abnormality. Percent survival was determined as the number of larvae surviving in each test container relative to the seawater control. Larvae that failed to transform to the fully shelled, hinged, "D-shaped" prodissoconch I stage were considered abnormal. The results of the dilution bioassay were also analyzed to estimate the 48-h median effective concentration (EC50) based on abnormal shell development.

Salinity, dissolved oxygen, and pH levels were initially adjusted in each container to 28 ppt, 7.6-7.8 mg/L, and 7.9-8.0, respectively.

These variables were measured for each container at the termination of the bioassays.

2.6 FISH HISTOPATHOLOGY

2.6.1 Field Sampling

Demersal fish assemblages in Commencement Bay and Carr Inlet were sampled June 4-9, 1984 aboard the RV KITTIWAKE. Fishes were collected using a 7.6-m (headrope) Marinovich otter trawl, having a body mesh size of 3.2 cm (stretched) and a cod-end liner mesh size of 1.3 cm. All trawling was conducted at a constant vessel speed of approximately 2.5 kn during daylight hours (i.e., 0630-1700).

English sole (*Parophrys vetulus*) larger than 225 mm total length (TL) were targeted for histopathological analysis. Larger fish were selected for analysis because Malins et al. (1982) found that lesion prevalences in English sole less than 2 yr old were substantially lower than prevalences in older fish. The present study therefore focused on fish most likely to be afflicted with liver disorders (i.e., fish ≥ 3 yr old).

At each of the 17 trawl transects, all target fish were removed from the total catch and pooled in a large bucket. Sixty individuals were then randomly selected for analysis, yielding 1,020 fish for the entire study. Each selected fish was sacrificed by a blow to the head, weighed (nearest g wet weight), measured (nearest mm TL), examined for grossly visible external abnormalities (e.g., lesions, scoliosis, fin erosion, parasites), and tagged with a code number. Following external examination, each fish was transferred to the shipboard laboratory for internal examination and liver removal.

In the laboratory, the abdominal cavity of each specimen was surgically opened to reveal the visceral organs. After all internal organs were inspected for the presence of grossly visible defects, the liver was removed in its entirety and placed on a stainless steel plate. With the use of stainless steel dissecting tools, the liver was cut into multiple sections and examined for the presence of lesions. The color of the organ was noted, a portion of the tissue was placed in 10 percent neutral buffered formalin for subsequent histopathological analysis, and the remainder of the liver was placed in vials and frozen for later chemical analysis. If hepatic lesions or discontinuities were noted, the section for histopathological examination was taken from the affected area. If the organ appeared to be normal, the section for histopathological examination was taken from the center of the liver at its broadest point. Following removal and dissection of the liver, the gonads were inspected and the sex of the fish was noted. The head was then removed, a tag bearing the accession number of the fish was placed in the left opercular chamber, and the head was frozen for subsequent age determination by otolith examination.

All fishes in the remainder of the catch at each station were identified to species and counted. All English sole not selected for histopathological analysis were measured (nearest mm TL) and counted.

2.6.2 Histopathological Examination

Each formalin-fixed liver sample was dehydrated in a graded series of ethanol, cleared in xylene, and embedded in paraffin. Two 4-um sections were made using a rotary microtome. One section was stained with hematoxylin and eosin. The remaining section was left unstained for possible future use.

Prepared slides were examined using conventional light microscopy. All observed abnormal conditions were verified by Mr. Mark Myers, the chief pathologist of the Environmental Conservation Division of the Northwest and Alaska Fisheries Center of the National Marine Fisheries Service (NMFS). This verification procedure ensured that results of the present study are comparable with those of past studies conducted in Puget Sound by the NMFS Environmental Conservation Division (e.g., Malins et al. 1980, 1982, 1984).

2.7 BIOACCUMULATION

2.7.1 Field Sampling

2.7.1.1 Specimen Collection--

Bioaccumulation analyses were conducted on English sole and cancrid crabs. Because of its economic importance, the Dungeness crab (*Cancer magister*) was the preferred invertebrate species. However, two confamilial species (i.e., *C. productus* and *C. gracilis*) were retained for possible analysis because it was uncertain whether adequate sample sizes of *C. magister* could be obtained at every station.

At each study site, five English sole were randomly selected from the 60 fish used for histopathological analysis (see Section 2.6). Each fish (whole body minus liver and head) was tagged with a code number, wrapped in aluminum foil, stored on ice, and returned to the shore-based laboratory for tissue removal.

Cancrid crabs were collected from the trawl catches at each study site. Crab pots were also fished near each trawl transect to provide additional specimens. Each crab (whole body) was tagged, placed in a polyethylene bag, held live on ice, and returned to the shore-based laboratory for tissue removal.

2.7.1.2 Tissue Removal--

English Sole--Each fish was first rinsed with tap water to remove any adherent contaminants and then scraped with a stainless steel spatula to remove surface mucus. The carcass was then placed on an absorbent pad and the upper fillet was removed with the skin intact. The carcass was then turned over and the opposite fillet was removed. Both fillets were placed skin-side down on a precleaned glass plate and the skin was removed using a stainless steel filleting knife. The skinned fillet was then cut into 6-g and 36-g portions, which were stored frozen in glass bottles for subsequent metal and organic analyses, respectively.

All instruments were stainless steel and were cleaned between use on each fish. The cleaning procedure consisted of washing with tap water to remove any adherent tissue, wiping clean with a sterile gauze pad, soaking in methylene chloride (nanograde), and finally rinsing with double-distilled, deionized water (tissue culture quality). Work surfaces were washed with 95 percent ethanol, followed by methylene chloride. With the exception of the external skin surface, each fish was handled with cleaned stainless steel instruments and came into contact with precleaned glass only.

To ensure that samples were not mixed, each specimen was identified and processed to completion before a second animal was started. This consisted of removing the identifying label that accompanied the carcass, labeling the final collection jars, and processing the entire specimen before beginning the next. The original identification tag accompanied the sample from the carcass to the final sample jar. All specimens from each collection site were stored as a group to ensure that specimens from different study sites were not mixed.

Cancrid Crabs--Each crab was first washed with tap water to remove surface contaminants and then dried using a paper towel. All legs were cracked off at the body suture and placed on a precleaned glass surface. Muscle tissue remaining inside the body was removed using curved stainless steel forceps and placed on the glass surface. The end of each leg was then cut with scissors and the muscle tissue was expressed by squeezing from one end of the leg toward the cut end. This tissue was added to the body tissue, mixed thoroughly, divided into 6-g and 36-g portions, and stored frozen in glass bottles for later metal and organic analyses, respectively.

All instruments and work surfaces were treated using the same procedures as those described previously for fish tissue removal. In addition, all crabs from each study site were processed individually and stored as a group to ensure that specimens from different study sites were not mixed.

2.7.2 Laboratory Analysis for Metals

2.7.2.1 Muscle tissue--

For the first set of muscle tissue analyses, a 2-g aliquot of wet tissue was used for analyses. The tissue was held overnight in HNO_3, then digested as for metals, and the digestate was diluted to 100 mL. Barium, beryllium, chromium, cobalt, copper, iron, manganese, nickel, silver, and zinc were analyzed by ICAP. Arsenic, cadmium, lead, antimony, selenium, and thallium were analyzed by graphite furnace with deuterium arc background correction. Mercury was analyzed on a separate 0.5-g aliquot using cold vapor atomic absorption.

Subsequent QA review of the data indicated that the aforementioned protocol had not been followed for the tissue analyses except for the mercury determinations. Consequently, many elements were not detected, and the detection limits reported were not as low as originally requested. Thus, reanalysis of the muscle tissue was required. Due to limited sample size, cadmium, chromium, copper, lead, nickel, and silver as elements of critical importance were requested for reanalysis. No tissue remained for one sample

(HY-71-560), and the remaining sample quantities varied from 0.38 g to 8.05 g wet weight. To obtain total solids measurements, the entire remaining sample was dried at 50° C prior to HNO_3/H_2O_2 digestion. The entire aliquot of dried tissue was digested using similar procedures as for the sediments. The resulting digestates were diluted prior to analysis such that the maximum dilution factor, based on sample weight, was 12.5. Analyses for chromium, copper, and nickel were performed by ICAP. Cadmium, lead and silver were analyzed by graphite furnace AA with deuterium arc background correction.

2.7.2.2 Fish Livers--

Approximately 0.5 g (wet weight) of liver tissue was digested using persulfate and analyzed for Hg using the cold vapor technique. The remaining liver tissue, consisting of samples sizes ranging from 1.04 g to 9.14 g, was dried at 60° C to obtain percent solids content and then digested using HNO_3 and H_2O_2. The digestates were diluted to 25 mL if less than 2 g was digested, or to 50 mL if more than 2 g was digested. Iron and zinc were analyzed for by flame atomic absorption. All other metals were analyzed by graphite furnace with Zeeman correction.

2.7.3 Laboratory Analysis for Organic Compounds

2.7.3.1 Volatile Organic Compounds--

Volatile organic compound analyses were conducted for 20 selected fish tissue samples using 1-g tissue aliquots blended with 3 mL of organic-free water and spiked with three recovery standards. The blended samples were transferred back into VOA vials and the tissue blender was rinsed twice with additional 3-mL aliquots of organic-free water. After addition of internal standards, the sample was analyzed according to the purge and trap technique described for sediments.

2.7.3.2 Semi-Volatile Organic Compounds--

Homogenized muscle and liver tissue samples were mixed with approximately 30 g Na_2SO_4 in a beaker prior to adding to precleaned Soxhlet thimbles for extraction. When possible, approximately 25 g of wet muscle tissue was used for analysis; some individual fish and most crab samples had less material (a minimum of 13 g wet weight crab muscle). Because of the limited mass of individual fish livers (1.5-3 g wet weight), liver tissue was composited from 6-40 fish (in samples used for replicate analyses) to yield 6-25 g wet weight for organic analyses. The same total amount of labelled recovery standards used to spike sediments (5 ug/component/sample) was also used for tissues. Although this amount resulted in a higher spike level (>400 ug/kg wet weight) than that used with sediments because less tissue sample was available, the same final dilution volume was required.

Fish and crab muscle tissue Soxhlet extracts were partitioned against acidified organic-free water as described for sediment extracts. Because of the simplicity of the extracts, the elemental sulfur removal step and SPE chromatography step used with sediments were omitted for tissues. GPC cleanup (Bio Beads) was required because of the high lipid content of the tissues, and was performed as described for sediments. All tissue extracts to be analyzed by GC/MS were taken to a final dilution volume of 0.5 mL following GPC; a one-tenth aliquot for PCB analysis by GC/ECD was taken to a final volume of 1 mL.

2.7.3.3 Total Extractable Organic Material--

The weight of solvent-extractable organic material in tissues was determined directly from the same extract used for chemical analyses. After allowing the Soxhlet extracts to settle overnight, a 1-mL aliquot was transferred to a pre-weighed aluminum dish, evaporated, and weighed. This aliquot was typically 1/200 of the total extract. The weight measurement of a smaller aliquot was not feasible because an electrobalance was not available for this analysis.

2.8 DATA MANAGEMENT

As part of the overall management support provided to WDOE, a data management system was developed for the Commencement Bay Nearshore/Tideflats Remedial Investigation. The system was designed to manage the large quantities of data that were collected and used for this investigation and to provide WDOE with a tool for long-term management of environmental data from Commencement Bay.

The data management system consists of a central database, additional data analysis capabilities, and a library. It was developed using an IBM microcomputer and the Knowledge Man relational database software package.

2.8.1 The Database

The Commencement Bay database consists of 23 data files, each storing a different type of data. Data of different types are linked by common identifiers. There are two sets of key identifiers: survey-station-sample and drainage. All data are identified by survey or research project, by a carefully located station, and by a description of the sample that was taken for analysis. In addition, data are identified by location within the Commencement Bay drainage system defined and described for this project (i.e., along a waterway, ditch, pipe, drain, or seep).

These two sets of identifiers make it possible to examine data from several points of view. Different data sets that are related in space and/or time can be retrieved easily in a form that enables comparison. For example, drainage identifiers can be used to retrieve all data for a given point source or to plot spatial changes in a variable (e.g., chemical concentration) along a creek, ditch, or aquifer. These latter capabilities were used extensively during the project for source identification.

Currently, the Commencement Bay database contains over 25,000 records, each consisting of 15-150 separate parameters. There are descriptions of over 50 surveys, 500 sampling stations, and 2,000 samples of water, solids, and biota. More than 400 components of the Commencement Bay drainage system have been identified. Types of data stored include inorganic and organic chemicals; conventional variables for both sediment and water; results of amphipod, oyster larvae, and bacterial bioassays; and observations on fish pathology and benthic community structure.

The large quantity of data is easily managed within the menu-driven system, which allows access to all files. The menus enable the user to enter, edit, view, report, or process data of any data type by simply typing one to three letters at each choice. Data from a particular station or sample can be retrieved quickly and viewed by selecting two or three descriptors.

2.8.2 Data Analysis

Standard reports are built into the menu-driven system. Reports can be simple or complex tables, forms, spreadsheets, or graphics. Reports are available to provide simple statistics and to calculate mass loadings. For non-standard, one-time requests, the database software contains a special "structured language" very close to English that allows a user to request needed information.

For more complex analyses, data retrieved via the menu-driven reports or ad-hoc queries can be written to a file in standard ASCII format. These retrievals can then be included in word-processed reports; used with other analysis programs, statistical packages, or models; or transferred to other computers via modem.

Data analyses conducted to apply decision criteria and to identify contaminant sources for Commencement Bay involved the use of the database and several auxiliary packages. The database was used to retrieve partial and entire data sets and to calculate statistics such as means and detection frequencies for chemical compounds, mean mortalities of bioassay organisms by station and by waterway, and counts of the number of fish with lesions of certain types. For source identification, the ability to search for data on the basis of drainage enabled retrievals of all historical data for a certain pipe or all data on a certain compound from a set of discharges to a waterway.

Data were also transferred via file to the SPSS/PC software package available for IBM microcomputers. This package was used extensively in running parametric and nonparametric statistical analyses (e.g., correlations, analyses of variance, t-tests, and factor analyses) as well as in calculating elevations above reference. Data were transferred to SPSS on a Prime minicomputer for performing cluster analyses, and several Fortran programs were used for other analyses.

2.8.3 Graphics

The LOTUS 1-2-3 spreadsheet was used to create graphics to display data. Spatial information stored for stations in the database enabled any data point to be placed at a position along a drainage. The spreadsheet was used to graph the concentration of a given contaminant against distance from the mouth of the waterway or drainage. In addition, the shoreline of Commencement Bay was digitized and the coordinates incorporated into spreadsheets. Maps of the area were then created. The scale of these maps can be adjusted and actual data values can be graphically presented on these maps.

2.8.4 Data Quality Control

Extensive quality control procedures were used in coding and entering data. All historical data considered for inclusion in the database were evaluated by technical personnel. All new data collected for the project were subjected to extensive quality assurance (QA) by technical personnel. Throughout the data-screening, coding, and entry process, data personnel worked closely with technical staff in properly coding data and qualifying data as indicated by QA review.

Data were entered into the database using forms identical to those used for coding. Extensive error trapping facilities were used, including a set of programs to check the entered data for errors in identifiers or codes. One hundred percent of all data collected to analyze sources and levels of contamination in Commencement Bay were verified after entry.

The database was designed to provide information about data quality and data interpretation along with the actual data. Data are referenced to the document containing the original data. This allows a user to return to the original source if desired. The initials and organization of the QA officer who reviewed the data are also stored. Codes for each particular analysis method are also stored so that later retrieval of data for a particular use could specify use of data analyzed by certain methods only.

2.8.5 Library

A Commencement Bay project library was established which contains over 500 pertinent documents, including technical and administrative reports, correspondence, maps, and references. A complete copy of all documents in the library is located in the WDOE Project Office in Olympia and at Tetra Tech's office in Bellevue. Documents are filed by accession number.

This information is linked to the database in an overall records and document management system. A file in the database stores information on the documents in the project library by their accession number. It is possible to search for documents by number, title, author, agency, any word in the title, and by subject area. All data within the database are referenced to a document, enabling a user to easily locate original sources if needed.

2.9 HEALTH AND SAFETY

A site-specific safety plan (Brown and Caldwell and E.V.S. Consultants 1983) was prepared for the data collection and field operations conducted under Tasks 3 and 4 of the Commencement Bay Nearshore/Tideflats Remedial Investigation. The safety plan was based on guidelines in Tetra Tech (1983b). Both plans were approved by the WDOE Project Manager and the U.S. EPA Region X Safety Officer.

Procedures described in the site-specific safety plan ensured safe collection of data of adequate quality to meet contract specifications. The plan specifically called for a modified Level D protection with the substitution of marine rubber work boots with non-slip soles for steel-toed boots. Monitoring equipment included an HNu photoionization detector and personnel organic monitoring badges. Collection of certain deep core and sediment samples required the use of respirators with GM C-H combination cartridges for acids, gases, and organic vapors (MSA 464 046). The site-specific safety plan includes the following sections:

- Introduction
- Site safety plan summary, Tasks 3 and 4
- Site description
- History of site activities
- Contractor's site safety work plan
- Hazard evaluation and potential chemical exposure
- Key personnel
- Work effort and levels of protection
- Designated work areas
- Personnel and equipment
- Site emergency procedures
- Emergency facilities
- Monitoring of air and personnel
- Personnel training
- Weather and other conditions which may affect site operations
- Access by unauthorized personnel
- Decontamination
- References.

2.10 SAMPLING AND ANALYSIS QA/QC

QA/QC procedures applied in the Commencement Bay Nearshore/Tideflats Superfund Investigation were geared to cover interdisciplinary field sampling, laboratory analyses, and data analysis/validation of over a million data values on approximately 28,000 data records. Specific procedures used in each of these areas were summarized in a QA/QC project plan approved by the U.S. EPA and WDOE (Brown and Caldwell and E.V.S. Consultants 1984). These procedures covered necessary collections of water, biota (fish and crab species), surface and subsurface sediments, and suspended particulate material for analyses in organic and inorganic chemistry, benthic ecology, sediment toxicology, and fish pathology.

Results from analytical laboratories were reviewed by Tetra Tech for conformance with QA/QC requirements and to resolve analytical problems. Detection limits, recovery, precision, completeness, and conformance with the specified protocol were verified during data review. Ten to twenty percent of the data was examined in a complete verification effort. The remainder of the data was evaluated for outliers and completeness prior to submission for database entry. All of the spectral data for the tentatively identified organic compounds were manually examined. When possible, QA audits included the use of known geochemical trends in environmental data to evaluate the reliability of the data returned for interpretation.

2.10.1 Sample Collection

Integration of field tasks and study results was accomplished by establishing common sampling sites, sampling methods, and sampling times for related disciplines, as specified in the project sampling and analysis plan (Tetra Tech 1984b). Field sampling procedures included instructions for navigation, geophysical investigations (bottom profiling), use of field sampling gear, sample container preparation, sample preservation and holding times, and shipping procedures. Special sample handling requirements to ensure the integrity of samples were also defined, for example, the need to exclude air spaces in the collection of sediments for volatile organics analysis. Sample alteration checklists were used to document authorized changes in previously established procedures in order to provide an accurate record for use in data interpretation. Sample custody records were maintained so that sample possession could be traced from the time of collection to the time of introduction as evidence in enforcement proceedings. Replicate archive samples of all sediment samples collected for analysis, and unanalyzed fish liver samples were maintained in freezers should additional analyses be warranted in the future. Selected formalin-preserved benthic taxonomy samples were retained to document a reference collection.

2.10.2 Organic Compound Analyses

A method validation study involving four laboratories was conducted to evaluate established analytical protocols of varying sophistication used for the determination of trace organic compounds in sediments. Based on the QA evaluation of these data, a modified protocol was recommended by Tetra Tech for use in the project in coordination with requirements of the U.S. EPA Contract Lab Program (CLP). The method of standard additions used in this protocol (the isotope dilution technique using 54 labelled recovery standards) enabled the correction for target compound losses during sample workup. Validation of this modified chemical protocol was accomplished by a step-wise verification of compound recoveries during each stage of the protocol before sample processing began. Recoveries of >80 percent for each stage were required and attained for almost all compounds in tests with spiked blanks.

The contract laboratory performing these analyses followed routine QC guidelines defined by the CLP and include:

- Documentation of GC/MS mass calibration and abundance pattern
- Documentation of GC/MS response factor stability
- Internal standard response and retention time monitoring
- Reagent blank analysis
- Surrogate spike response monitoring
- Matrix spike and duplicate analysis (one each per 20 samples).

Specific procedures regarding the laboratory performance requirements are stated in the IFB WA 84A-266 contract and in special analytical services (SAS) contract 864J. Additional quality control checks included analysis of "blind" replicates for sediment and biological tissue. Because of the small sample size, no "blind" replicates or matrix spikes were performed on the particulate filters. A summary of available data on precision of recovery-corrected concentrations in different samples and the recovery of isotopically labeled recovery standards spiked in each sample is provided in Table 2.3. Precision of the recovery-corrected values was calculated only when compounds were detected in samples. Not all chemicals were detected in each set of replicate samples.

A list of tentatively identified compounds was compiled from detailed analysis of 17 preliminary samples. The compounds were specifically "searched" for in all the sample extracts. All the spectral data for these compounds were manually examined.

2.10.3 Trace Metals and Ancillary Analyses

The laboratories performing these analyses followed routine QC guidelines defined by the U.S. EPA contract laboratory program and include:

- Documentation of initial and continuing calibration for each metal
- Documentation of instrument detection limits
- Procedural blank analysis
- Matrix spike and duplicate analysis (one each per 20 samples).

Specific procedures regarding the laboratory performance requirements are stated in the IFB WA83-A125 contract and special analytical services contract 864J. Additional quality control checks included the analysis of "blind" replicates for sediment and biological tissue. Duplicate blind replicates and matrix spikes were not performed on the filters due to the limited sample size. The National Bureau of Standards standard reference material (SRM) bovine liver was submitted for analysis with the fish livers. Oyster tissue SRM was submitted with fish tissue. A summary of available precision and recovery data is provided in Table 2.4. The results of the analysis of the bovine liver SRM caused the values for arsenic and lead in fish liver to be qualified as questionable.

The precision of ancillary sediment data accepted was within QA requirements as demonstrated by replicate analyses for percent solids (mean ± 2.7 RPD), volatile solids (mean ± 2.3 RPD), total organic carbon (mean ± 5.6 RPD), and nitrogen (mean ± 3.6 RPD). Sulfide and oil and grease analyses showed greater variability with ± 39 RPD and ± 30 RPD, respectively. Sulfide results are used only as a semi-quantitative measurement in these reports because of lab holding time and preservation problems.

2.10.4 Benthic Macroinvertebrates, Sediment Bioassays, and Fish Histopathology

The QA procedures for these analyses are described in Sections 2.4, 2.5, and 2.6.

2.11 RISK ASSESSMENT

"Risk assessment" is a descriptive term applied to an analysis of hazard potential in an environment. All risk assessments have two elements in common:

TABLE 2.3. SUMMARY OF AVAILABLE PRECISION AND RECOVERY DATA FOR COMMENCEMENT BAY ORGANIC CHEMISTRY SAMPLES

	Surface Sediments	Subsurface Sediments	English Sole	
			Muscle	Livers
	Precision[a] (Mean Coefficient of Variation)			
Phenols	± 52	± 42	-	-
Aromatic hydrocarbons	± 17	± 18	-	-
Chlorinated hydrocarbons	± 25	± 41	-	-
Total PCBs	± 42	± 15	± 11	± 15
Phthalates	± 61	± 44	± 100	-
Miscellaneous compounds				
Benzyl alcohol	± 54	± 42	-	± 34
Dibenzofuran	± 17	± 9	-	-
	Percent Recovery[b]			
Phenols	47 (59)	69 (67)	17 (67)	-
Aromatic hydrocarbons	80 (99)	60 (94)	33 (98)	-
Chlorinated hydrocarbons	31 (120)	17 (140)	11 (124)	-
Phthalates	71	59	44	-

[a] Precision determined by multiple sets of replicate analyses. Value shown is mean coefficient of variation in sets of replicates with detected values (recovery corrected).

[b] Values shown are mean percent recoveries of isotopically labeled compounds added in quantities within a factor of ten of the lower limit of detection. The values in parentheses are the mean percent recoveries obtained from multiple matrix spike samples. The matrix spike compounds were added at levels several times higher than the isotope recovery standards.

TABLE 2.4. SUMMARY OF AVAILABLE PRECISION AND RECOVERY DATA FOR COMMENCEMENT BAY INORGANIC CHEMISTRY SAMPLES

	Precision (Mean RPD)[a]			Percent Recovery		
	Surface Sediment	English Sole Muscle	English Sole Livers	Surface Sediment[b]	English Sole Muscle[c]	English Sole Livers[d]
Antimony	± 14	-	-	92	-	-
Arsenic	± 8.1	± 24	± 35	89	-	360[e]
Barium	± 3.3	-	± 46	99	-	-
Beryllium	± 2.4	-	-	99	-	-
Cadmium	± 4.7	-	± 12	97	87	140
Chromium	± 6.3	-	± 29	99	90	-
Copper	± 5.0	-	± 12	98	100	90
Lead	± 5.5	-	± 56	100	115	450[e]
Iron	± 2.4	-	± 11	-	-	100
Manganese	± 2.7	± 7.6	± 7.3	100	-	-
Mercury	± 8.2	± 12	± 5.6	100	-	-
Nickel	± 8.5	-	± 32	98	84	-
Selenium	-	± 38	± 62	79	-	-
Silver	± 17	-	± 32	90	100	-
Thallium	± 0	-	± 20	87	-	-
Zinc	± 36	± 7.0	± 20	100	-	64

[a] Precision determined by multiple sets of replicate analyses. Values are mean relative percent differences in sets of replicates with detected values.

[b] Recovery determined by multiple analyses of matrix spike samples. Values are mean relative percent recoveries.

[c] Recovery determined by multiple analyses of standard reference material (oyster tissue). Values are mean relative percent recoveries.

[d] Recovery determined by multiple analyses of standard reference material (bovine livers). Values are mean relative percent recoveries.

[e] Because of the high recoveries of arsenic and lead relative to the certified reference material, all data values for these substances in fish livers were qualified as questionable.

- An assessment of exposure to one or more substances
- An assessment of the hazard associated with exposure to a substance or collection of substances.

These two elements must then be integrated into an analysis of the level of risk experienced by a group, or population. This integration can be accomplished on different levels: the risk to each exposed individual over a lifetime can be calculated, or the cumulative risk to the entire exposure population can be predicted as the total number of illnesses expected over a 70-yr period.

Each major step in the risk assessment process (i.e., exposure evaluation, hazard evaluation, and risk calculation) is discussed individually in the following sections.

2.11.1 Exposure Evaluation

This analysis addresses three types of exposure: ingestion of fish muscle tissue, ingestion of crab muscle tissue, and ingestion of fish livers. Ingestion of fish and crab muscle tissues are analyzed differently from ingestion of fish livers.

2.11.1.1 Exposure to Contaminants in Fish and Crab Muscle Tissue--

There are two elements to assessing exposure to the population eating fish and crabs from Commencement Bay: 1) estimating the exposure population and 2) estimating the rate of fish and crab ingestion. Estimates of these elements rely on data from the Tacoma-Pierce County Health Department (TPCHD).

The TPCHD conducted a survey of recreational anglers in 1981, questioning survey participants on the amount and type of fish they catch, the frequency of their fishing, and their plans for the catch (whether they planned to eat it). This catch/consumption survey was conducted during the late summer and fall of that year, and focused on shore fishing activities.

The catch/consumption survey is detailed in a report by Pierce et al. (1981). The authors (Pierce et al. 1981) concluded that 2,900 persons fished the shores of Commencement Bay, with varying frequency, in that year. The estimate did not include results of the abbreviated survey of persons fishing from boats. For this analysis, results from that part of the survey have been adjusted for seasonal frequency following the method of Pierce et al. (1981) for shore fishing. The frequency of boat fishing was assumed to be equal to the frequency of shore fishing. The number of persons fishing from boats (an estimated 1,170) was added to the number fishing from shore to derive a total of 4,070 anglers. It was assumed that the shore fishing and boat fishing populations did not overlap and that persons fishing were not "double counted." It is quite likely, however, that the addition of boat anglers resulted in an overestimate of total exposed population. Pierce et al. (1981) reported that the average family size is 3.74 persons. Assuming that all members of a family eat fish, the total exposed population would be 4,070 x 3.74, or approximately 15,200 persons.

Data from Pierce et al. (1981) also enable estimation of the frequency of fishing, which (when combined with a value from the survey on average catch per fishing trip) can be keyed to the amount of fish and crabs eaten. A frequency distribution of fish muscle tissue ingestion rates from this survey is presented in Table 2.5. The maximum ingestion rates reported by Pierce et al. (1981) are used throughout this report as a basis for estimating contaminant exposure. The risk assessment is keyed to this table, because the risk to persons eating Commencement Bay fish and crabs daily is considerably different from the risk to persons fishing only once or twice a year and eating those fish. No data on shellfish (i.e., crab) consumption were available for Commencement Bay. Consumption of crab was therefore assumed to follow a distribution equal to fish consumption.

Rates of fish and crab ingestion (g/day) were multiplied by the average level of contaminant (ug/g of fish) to yield exposure (ug/day). Exposure calculations in this assessment were based on a number of scenarios. The average level of contaminant in fish was calculated for:

- Each station from which fish or crabs were collected for analysis
- Each waterway or study area (all stations within that area combined)
- All nearshore/tideflats stations together.

In all cases, the method detection limit was used in the calculation of means if a substance was not detected.

For this analysis it was assumed that the fish and crabs examined for contaminants were representative of those ingested by persons fishing in Commencement Bay. However, all fish analyzed were English sole, which are not commonly eaten and are among the most contaminated fish species in Commencement Bay (see Section 3.6, Bioaccumulation). All shellfish analyzed were Dungeness crabs and rock crabs. Data were not sufficient to state that crabs were either more or less contaminated than other types of shellfish in the Bay.

2.11.1.2 Exposure from Ingestion of Fish Livers--

A subgroup of special interest in this assessment was the population that eats fish livers. Although this group is believed to be small, its exposure to contaminants in Commencement Bay fish may exceed that of the group eating muscle tissue because many chemicals are known to concentrate in the liver.

The assessment of exposure from eating livers was based on the maximum observed chemical concentrations in composite samples of livers from fish captured at the trawl transects in the bioaccumulation study (see Section 3.6). Means were not used because several livers were pooled for each chemical analysis, and the maximum observed values actually represent the mean of several liver samples.

TABLE 2.5. POPULATION EXPOSED BY CONSUMPTION RATE

Frequency	Frequency Percent	Ingestion Rate	Intake g/day	Population Exposed
Daily	0.2	1 lb/day	453.0	30
Weekly	6.6	1 lb/wk	64.7	1,005
Monthly	11.4	1 lb/mo	15.1	1,735
Bimonthly	7.3	1 lb/2 mo	7.4	1,111
Semiannually	17.2	1 lb/6 mo	2.5	2,618
Annual	57.3	1 lb/yr	1.2	8,721
Total	100.0			15,220

Reference: Pierce et al. (1981).

No data on the quantity of fish liver eaten were available. It was therefore assumed that the amount of liver eaten is proportional to the amount of fish muscle eaten (i.e., that persons who eat fish livers consume the livers from all fish they catch and consume). The average proportion of liver weight to muscle weight for 13 species of Commencement Bay fish is 0.12 (Gahler et al. 1982), the factor used in this analysis in scaling exposures. Data on liver consumption rates as a function of muscle tissue consumption rates are presented in Table 2.6.

2.11.2 Health Effects (Hazard Assessment) Methodology

Carcinogenic and noncarcinogenic health effects of U.S. EPA priority pollutants are summarized in Table 2.7. These effects are associated with different types of data and are treated differently in the risk assessment process. Although some chemicals have multiple effects, only the most significant (in severity or in terms of occurring at the lowest dose) are discussed.

"Carcinogens" in this assessment are substances that the U.S. EPA considers possible cancer-causing agents; they have not been implicated as causes of cancer in humans in all cases. Most of the available data are derived from animal studies, for both evidence and strength of carcinogenicity. It is generally assumed that carcinogens do not exhibit threshold effects (i.e., any exposure, no matter how low, can be associated with a quantifiable cancer risk). The potency of the carcinogen is expressed as a risk score, which is the probability of effect per unit dose of chemical, in units of $(\mathrm{mg/kg/day})^{-1}$. The unit cancer risk scores in this study are those published by the U.S. EPA's Carcinogen Assessment Group (U.S. EPA 1984).

Noncarcinogens are usually assumed to exhibit thresholds (i.e., to cause some ill effect only after a certain dose is exceeded). That dose is termed the No Observed Effect Level (NOEL). Since NOELs have been derived almost exclusively from studies of small mammals, the measured NOEL is usually divided by a safety factor to derive a level that can be considered safe for humans. The safety factor takes into account the variability in toxicity of a chemical between the experimental species and humans, variability within the human population, and deficiencies in the experimental data. The safety factor usually reflects a chronic, 70-yr exposure. This resulting value is termed the Acceptable Daily Intake (ADI) and was used in this assessment. Effects are considered possible in a sensitive subpopulation when the exposure or dose exceeds the ADI (i.e., if the ratio of exposure to the ADI equals or exceeds 1). ADIs are set for chronic (i.e., 70-yr) exposure. Safety factors range from 1 [for high-quality data, based on long-term human exposure (usually occupational)] to 1,000 (if the original health data are from short-term studies of small lab animals).

2.11.3 Risk Assessment Calculations

The exposure and effects data discussed above were combined in this step of the assessment to calculate risk to the individuals ingesting fish from Commencement Bay. Risk was assessed on a chemical-by-chemical basis. Chemicals may interact with one another to produce synergistic effects (magnifying the probability or severity of an effect), additive effects

TABLE 2.6. FISH LIVER CONSUMPTION RATES

Frequency	Fish Consumption g/day	Liver Consumption g/day
Daily	453.0	54.4
Weekly	64.7	7.8
Monthly	15.1	1.8
Bimonthly	7.4	0.9
Twice/year	2.5	0.3
Yearly	1.2	0.1

Reference: Derived from Pierce et al. (1981) and Gahler et al. (1982).

TABLE 2.7. A SUMMARY OF HEALTH EFFECTS DATA FOR CARCINOGENS AND NONCARCINOGENS

CHEMICAL CARCINOGENS	RISK SCORE per mg/kg/day	HEALTH EFFECT
acrylonitrile	0.552	brain tumors
aldrin	11.4	liver tumors
arsenic	14	skin cancer
benzene	0.052	leukemia
benzidine	234	bladder cancer
beryllium	4.86	leukemia
carbon tetrachloride	0.083	liver tumors
chlordane	1.61	liver cancer
chromium	41	when inhaled; no value for ingested
hexachlorobenzene	1.67	liver tumors
dichloroethane (1,2)	0.037	circulatory hemangiosarcomas
trichloroethane (1,1,2)	0.0573	hepatocellular carcinomas
trichloroethane (1,1,1)	0.0016	liver tumors
tetrachloroethene	0.035	liver tumors
trichloroethene	0.019	liver tumors
tetrachloroethane (1,1,2,2)	0.201	hepatocellular carcinomas
hexachloroethane	0.0142	hepatocellular carcinomas
trichlorophenol (2,4,6)	0.0199	hepatocellular carcinomas, adenomas
chloroform	0.183	hepatocellular carcinomas
DDT	8.42	liver adenocarcinoma
dichloroethylene (1,1 and 1,2)	1.04	kidney adenocarcinoma
dieldrin	30.4	liver tumors
dinitrotoluene	0.311	mammary tumors, hepatocellular carcinoma
tetrachlorodioxin	425000	hepatocellular and other carcinomas
diphenylhydrazine	0.768	hepatocellular carcinomas and adenomas
halomethanes	0.183	liver tumors
heptachlor	3.37	hepatocellular carcinoma
heptachlor epoxide	3.76	hepatocellular carcinoma
hexachlorobutadiene	0.0775	renal tubular adenoma and carcinoma
hexachlorocyclohexane (HCH)	4.75	liver tumors
alpha	11.1	liver tumors
beta	1.84	liver tumors
gamma (Lindane)	1.33	liver tumors
dimethyl nitrosamine	25.9	liver cancer
diethyl nitrosamine	43.5	liver cancer
dibutyl nitrosamine	5.43	bladder and esophogeal cancer
NN diphenylamine nitrosamine	0.0049	bladder tumors
N-nitrosodipropylamine	31	mammary tumors and hepatocarcinoma in mice
dibenzo(a,i)pyrene	476	lung cancer-inhalation
benzo(a)pyrene	11.5	stomach papillomas, carcinomas
DEHP	0.0141	liver,kidney cancer
PCBs	4.34	hepatocellular carcinoma
toxaphene	1.13	hepatocellular carcinoma and adenoma
tetrachloroethylene	0.04	hepatocellular carcinoma
trichloroethylene	0.0126	hepatocellular carcinoma
vinyl chloride	0.0175	liver angiosarcoma
BCEE	28	various carcinomas

TABLE 2.7. (Continued)

CHEMICAL NONCARCINOGENS	ADI ug/day	SAFETY FACTOR	HEALTH EFFECT
acrolein	1100	1000	unknown via oral exposure
DDD	3010	1	hunched appearance, increades urination
DDE	350	1	hepatic necrosis in rats
a-endosulfan	280	100	brain and kidney damage
b-endosulfan	280	100	brain and kidney damage
endosulfan sulfate	280	100	brain and kidney damage
endrin	70	100	nervous system, leukocytosis, kidney degeneration
endrin aldehyde	70	100	nervous system, leukocytosis, kidney degeneration
antimony	292	100	altered blood chemistry
cadmium	700	?	renal tubular necrosis in humans
chromium-VI	175	1	kidney tubular necrosis
chromium-III	357000	1	sterility
cyanide	330	100	hypoxia (oxygen blockage)
lead	100	?	brain dysfunction and anemia in humans
mercury	20	10	ataxia,cerebellar atrophy, impaired vision in humans
manganese	10000	?	neurological dysfunction in humans
nickel	1460	1000	fetal mortality or reduced body weight
selenium	700	10	liver and endrocrine gland effects
silver	16	5	kidney hemorrhage, liver, stomach, and intestine damage
thallium	37	1000	nerve, kidney, liver, and stomach damage
zinc	15000	100	copper deficiency and anemia in humans
fluorotrichloromethane	201000	10	cardiac arrythmia
dichloroethane (1,1)	8100	?	liver function changes
dichloropropane (1,2)	980	1	liver function changes
dichloropropane (1,3)	180	1000	liver function changes
dichloropropylene (1,3)	180	1000	liver function changes
hexachlorocyclopentadiene	36	100	no oral effects known
bis 2-chloroisopropyl ether	70	10	no oral effects known
chlorobenzene	1008	1000	nervous system depression; liver, kidney necrosis
dichlorobenzene (1,2)	107000	100	cirrhosis of liver
dichlorobenzene (1,3)	140000	100	cirrhosis of liver
dichlorobenzene (1,4)	161000	100	cirrhosis of liver
trichlorobenzene (1,2,4)	464	10	liver metabolism changes in monkeys
ethylbenzene	1600	1	weight increase, kidney effects
nitrobenzene	4000	10	blood cyanosis in humans by inhalation or dermal exposure
toluene	134000	100	nervous system effects and cardiac arrythmia
total xylenes	160000	10	maternal toxicity
phenol	6800	500	kidney and liver damage
chlorophenol	6900	1000	increased nervous response in humans
dichlorophenols	7000	1000	convulsions in cats
pentachlorophenol	2100	100	micro-level changes in human liver and kidney via inhalation
nitrophenols	140	1000	effects unknown
dinitrophenol	140	1	numerous for 2,4- eyes, skin, nerves, liver, spleen in humans
dimethylphenol	7000	190	liver, spleen pathology
dinitro-o-cresol	71	10	effects on human skin when inhaled
diethylphthalate	875000	100	decreased growth
dimethylphthalate	1800	10	kidney effects on humans when inhaled
di-n-butylphthalate	1800	10	brain abnormalities in humans when inhaled
di-n-octylphthalate	1800	10	effects unknown
acenaphthene	18	?	enzyme blood changes in humans when inhaled
fluoranthene	420	1	mortality at high dose via dermal contact
naphthalene	18000	10	cataracts in humans (inhalation), rats (oral)

Reference: U.S. Environmental Protection Agency (1983, 1984) (combining similar effects of two chemicals), or antagonistic effects (preventing an effect entirely or lessening its severity). However, evidence of these interactions is relatively weak. Furthermore, while the combined effect of two chemicals may be known, the combined effect of the complex mixture of Commencement Bay pollutants is unknown.

2.11.3.1 Calculation of Carcinogenic Risk--

The first step in the assessment of carcinogenic risk was to calculate the exposure of an individual to a contaminant. Exposure was calculated as:

$$E = CI/W$$

where:

E = Exposure, mg/kg/day
C = Contaminant concentration, mg/kg
I = Ingestion rate, kg/day
W = Human weight, kg (assumed 70 kg).

The exposure was then used to calculate individual risk as:

$$R_i = BE$$

where:

R_i = Individual lifetime risk
B = Risk score, $(\text{mg/kg/day})^{-1}$.

Individual risk can be multiplied by the number of persons exposed at that level to estimate the total number of persons expected to develop cancer among the exposed population over the 70-yr lifetime. That calculation was not performed for all chemicals in this risk assessment. It was performed only for the chemicals with the highest absolute risks because other chemicals resulted in very low risks that were well below the health risk criterion (i.e., one predicted cancer case in the exposed population).

2.11.3.2 Noncarcinogenic Risk Calculations--

Because noncarcinogenic chemicals exert a threshold effect, the assessment of risk at a calculated level of exposure was performed by comparing the exposure to the ADI. If exposure exceeded the ADI, all persons exposed at that level were assumed to be affected. If exposure was equal to or less than the ADI, none of the individuals were assumed to be affected. There is no provision in this method for degree of effect. However, to a limited degree, the ratio of exposure to the ADI indicates the weight of evidence of projected effects.

2.12 SOURCE IDENTIFICATION

2.12.1 Sediment Chemistry

2.12.1.1 Surficial Sediment Chemistry--

All source identification efforts were initiated by an assessment of the magnitude and spatial extent of contamination in the surficial sediments of defined problem areas. The spatial gradient of contamination was evaluated to determine the probable location of the contaminant sources. The implicit assumption in this evaluation was that sediments with the highest levels of contamination (with appropriate normalization, as discussed below) were closest to the contaminant sources. It is recognized that in certain high-energy environments, physical transport processes may alter the contaminant distribution so that the greatest level of contamination does not necessarily coincide with the location of the contaminant source. Within the waterways of Commencement Bay, tidal action provides the only effective mechanism of contaminant dispersal. Therefore, it is reasonable to assume that environmental release of a contaminant would be reflected in nearby sediments, particularly if that contaminant has a high affinity for adsorption to sediment particles or organic matter, as do many of the contaminants of concern.

The spatial gradient of contamination was used both to determine the location of contaminant sources and to suggest probable routes of contamination. The guidelines used in this assessment are shown below. Final determinations of probable sources and routes of contamination required the integration of a great diversity of data and final assessments were made on a case-by-case basis. General guidelines for source identification efforts included:

- A localized area of contamination close to a known industrial outfall, storm sewer, or other discharge implicated that discharge as a potential source.

- A localized contaminant "hot spot" far from any identified potential source suggested the occurrence of a spill or exposed sediments from an unidentified historical source.

- A localized area of contamination in the general vicinity of a potential source but not immediately adjacent to an outfall suggested groundwater as one of the potential sources. Historical waste disposal practices on nearby properties were examined. A spill or historical source represented other possible explanations.

- Contaminant concentrations that decreased from the mouth of the waterway to the head suggested either the presence of a source very near the mouth or advection of the contaminant into the waterway from other areas.

Sediment contaminant concentrations are typically expressed as the weight of the contaminant per dry weight of sediment (hereafter referred to as "dry-weight basis"). In some cases, it was also valuable to normalize the concentrations using some other sample variable (see Section 3.1.2). For example, metals concentrations are sometimes shown on a dry-weight basis and normalized to percent fine-grained sediment (silt and clay), since metals generally have a high affinity for the finer silt and clay particles. This normalization is reported in the present study of sources only when the normalized data show a trend not apparent in the distribution of dry-weight concentrations. Organic compound concentrations are typically shown on a dry-weight basis and normalized to the total organic carbon content of the sediments, since the organic compounds of concern generally have a high affinity for organic material. Normalization of organic compounds by sediment organic carbon content can help reduce the effects of variable sediment texture on the interpretation of contaminant spatial trends. These data are also useful in evaluating the influence of organic enrichment on contaminant accumulations.

Normalizations of sediment chemistry data to account for variations in grain size or organic carbon content are used in interpretations only when they provide additional information not apparent in the spatial pattern of dry-weight concentrations. Large amounts of wood chips or slag in the sediments could also reduce the usefulness of these normalizations.

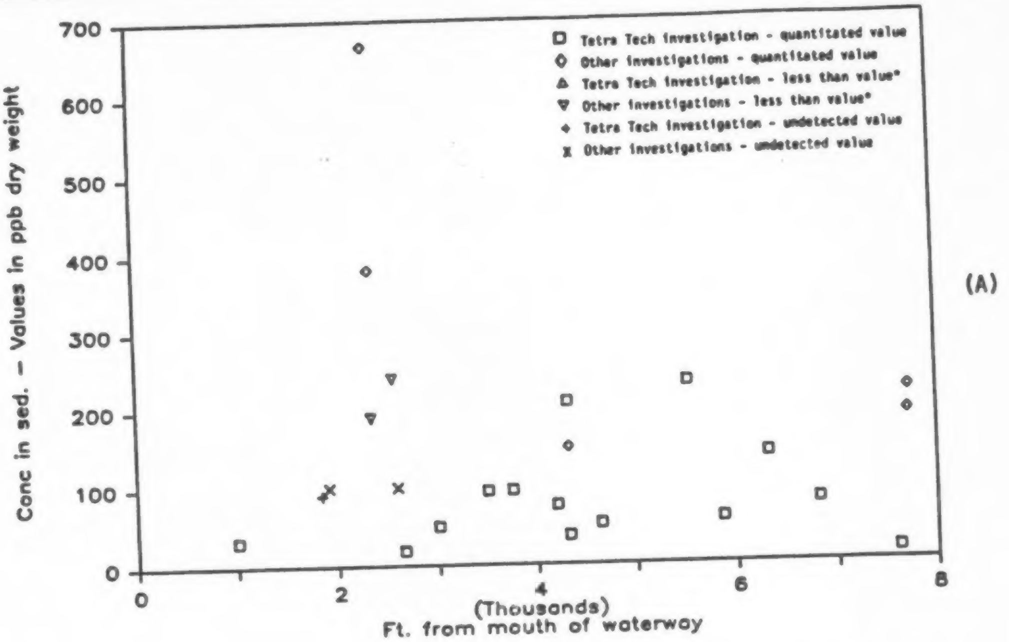
Throughout the source evaluation section (Section 7), two formats are used for presentation of surficial sediment chemistry data: 1) a graph of contaminant concentration versus distance from waterway mouth, and 2) a plan view of the relevant study area showing location of the sampling stations and the contaminant concentrations at each station (Figure 2.8). The concentration versus distance graphs were used only for long, linear waterways (Hylebos and City) when contaminant gradients along the length of the waterway were of primary interest. Plan views were used for all areas of concern, and were particularly valuable in identifying cross-waterway gradients of contamination. In some cases, plan views were used during data analysis and only critical features are summarized in text.

Three data types are differentiated on the graphs of concentration versus distance: 1) quantified contaminant concentrations; 2) "less than" values when a single compound was above a detection limit and below a quantification limit or when one member of a compound group was unquantified; and 3) undetected values, in which case the detection limit is shown. Source of the data is further differentiated on the graphs. In a few cases, data are not shown on the figures because they were from laboratory analyses with disproportionately high detection limits. Criteria for exclusion are provided below:

- For individual substances (or traditionally defined mixtures such as PCB Aroclors), undetected values at a detection limit greater than 100 ppb that also exceeded the 80th percentile of detected values were eliminated from the graphs.

- For groups of substances, data values for group totals were excluded from graphs if:

    - The average detection limit of the individual undetected components exceeded 100 ppb, and



*For single compounds a less than value indicates the compound was present at a concentration above the detection limit but below the quantitation limit. For compound groups, a less than value indicates one or more members of the group was below the detection or quantitation limit.

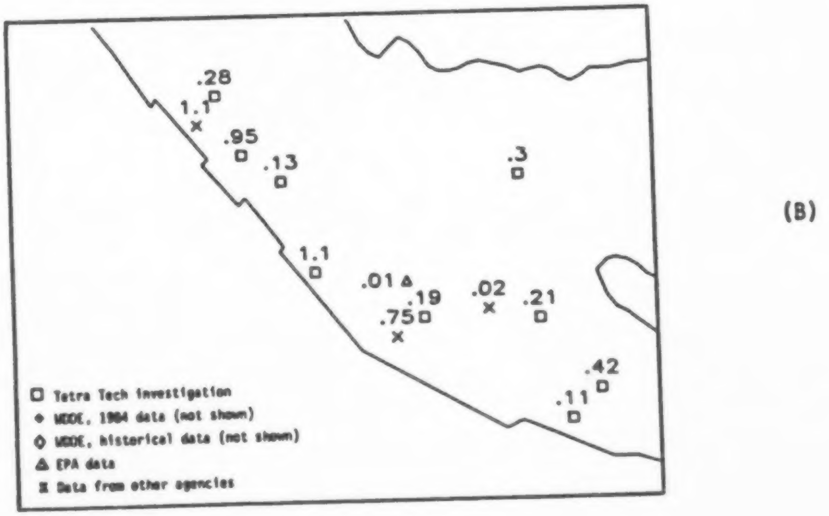

.28
1.1
.95
.13
.3
1.1
.01
.19
.75
.02
.21
.42
.11
□ Tetra Tech investigation
◆ WDOE, 1984 data (not shown)
◇ WDOE, historical data (not shown)
△ EPA data
x Data from other agencies
(B)

Figure 2.8. Examples of surficial sediment chemistry data.

- The sum of the detection limits for undetected components in the group was greater than 50 percent of the total value for the group, and

- The group sum also exceeded the 80th percentile of group sums where all components were detected or where undetected components constituted less than 50 percent of the total.

Plan views of the study area showing station locations and contaminant concentration at each station (Figure 2.8) were shown when cross-waterway gradients provided the most information about source location. Data shown on these figures were subject to the same review process described above. "Less than" or undetected values were indicated by "L" or "U," respectively. Station locations are shown by symbols indicating the agency responsible for collecting the data.

2.12.1.2 Sediment Cores--

Box core and gravity core samples were taken to obtain information on the vertical distribution of contaminants within the sediments (see Section 2.2.1) and on temporal changes in contaminant input to the waterways. Several guidelines were used in this assessment:

- Greatest contaminant concentrations in the uppermost horizon suggested an ongoing or a recent contaminant input.

- Subsurface contaminant maxima suggested that the greatest contaminant inputs had occurred historically or that the area had recently been covered by clean material (e.g., by dredging activity).

- Elevated contaminant concentrations within a single discrete horizon suggested that a spill, or a discharge of short duration was responsible.

- Uniformly elevated contaminant concentrations throughout the sediment column suggested either long-term contaminant input, contamination via groundwater percolating up through the sediments, or mobility of the compound in interstitial water.

For closely spaced core samples (e.g., in lower Hylebos Waterway), data from only one representative core sample are illustrated and the comparability of the other cores is discussed. All available core data were considered.

Sediment core data are usually presented in tabular form in Section 7. Data from several compounds in multiple cores are presented as illustrated as in Figure 2.9. A logarithmic scale was used because contaminant concentrations with depth typically varied over an order of magnitude or more. Although concentrations on both a dry-weight and normalized basis were considered, only concentrations on a dry-weight basis are shown to simplify the graph. Only one contaminant concentration per horizon is shown, since sediments from throughout the horizon were homogenized before analysis.

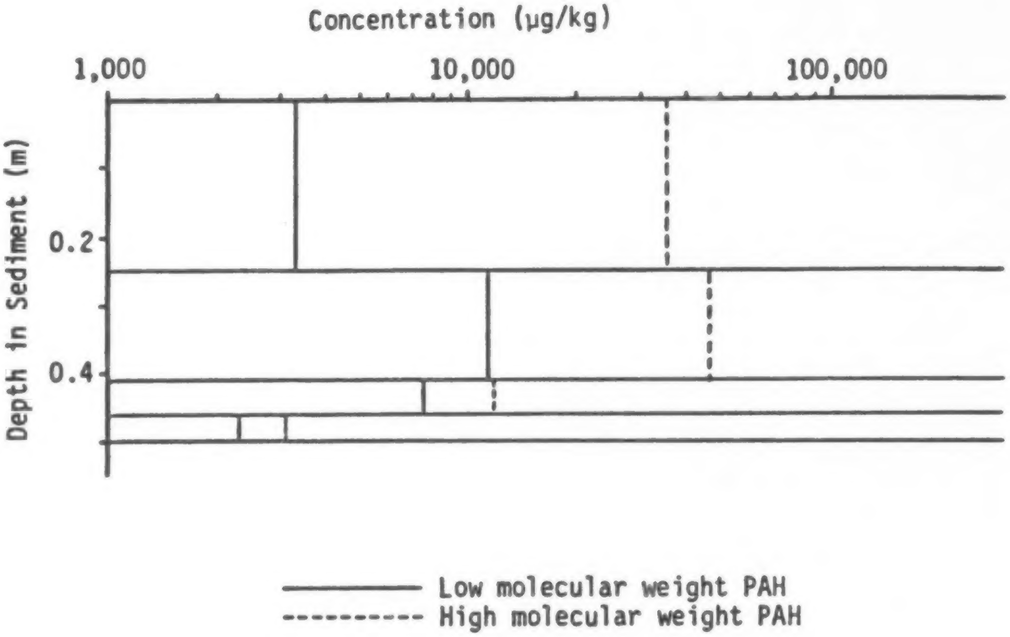


Figure 2.9. Example of sediment core data illustrating concentrations of PAH with depth in sediment at a site within Hylebos Waterway.

It should be recognized that contaminant concentrations could vary within any given depth interval.

2.12.2 Water Quality Data

Contaminant concentration of suspended particulates were determined for samples collected during water quality surveys of April and August, 1984. For organic compounds, the utility of these data in source identifications was limited because concentrations were usually below detection limits (except for some PAH). Metals concentrations were typically above detection limits. For contaminants with quantifiable concentrations, these data were used as ancillary information in source identification efforts. The data were used to estimate the importance of contaminant advection between Commencement Bay and the individual waterways.

2.12.3 Point Sources and Runoff

The contribution of contaminants by point sources and runoff was assessed by use of loading estimates. These loading estimates were calculated from all available measurements of discharge flow rate and contaminant concentration in the Commencement Bay database. The majority of discharge flow and concentration measurements in the database have come from WDOE investigations (e.g., Class II surveys) and Commencement Bay Nearshore/Tideflats Remedial Investigation studies. Other discharge-related data were available from surveys conducted by U.S. EPA, Tacoma-Pierce County Health Department, and specific industries. A thorough discussion of the discharge-related data in the Commencement Bay database is provided in Tetra Tech (1984b). Data appear in Appendix XV.

For each contaminant of concern, an average loading was calculated for each discharge into the defined problem area for which flow and concentration data were available. Because of the diversity of discharge data sources and the variability in data gathering and reporting methods, guidelines were established to ensure consistency in calculating average contaminant loadings. Procedures were established to deal with: 1) unmeasured flow rates; 2) undetected values; 3) detected but unquantitated concentrations ("less than" values) for single compounds; 4) loading estimates for a contaminant group when one or more members of the group were undetected; 5) loading estimates for a contaminant group when one or more members of the group were unquantitated; and 6) loading estimates for a contaminant group when one or more members of the group were unmeasured. These procedures are discussed below and are illustrated in Figure 2.10.

- Unmeasured Flow Rates: An average contaminant loading for a discharge was determined by calculating an average of all available flow measurements and an average of all concentration measurements for the contaminant of concern. The average flow and average concentration were then multiplied together, with appropriate adjustments for units, to obtain an average loading. This procedure allowed maximum use of all available data. In particular, it permitted the use of concentrations for which there was no coincident flow measurement.

1. UNMEASURED FLOW RATES

Sampling Event	Flow (MGD)	Contaminant Concentration (µg/l)
1	0.5	9
2	1.5	5
3	not measured	25
	$\bar{X}$ = 1.0	$\bar{X}$ = 13

Avg loading = 1.0 x 13 x 0.00834 = 0.11 lbs/day

0.00834 = conversion factor for micrograms to pounds and gallons to liters

2. UNDETECTED VALUES

1	0.5	2
2	1.5	undetected at 30
3	1.0	5
	$\bar{X}$ = 1.0	$\bar{X}$ = 3.5

Avg loading = 0.029 lbs/day

3. DETECTED BUT UNQUANTITATED CONCENTRATIONS ("LESS THAN" VALUES) FOR SINGLE COMPOUNDS

1	0.5	2
2	1.5	10
3	1.0	<9
	$\bar{X}$ = 1.0	$\bar{X}$ = <7

Avg loading = <0.058 lbs/day

4. LOADING ESTIMATES FOR A CONTAMINANT GROUP WHEN ONE OR MORE MEMBERS OF THE GROUP WERE UNDETECTED

Sampling Event	Flow (MGD)	Concentration (µg/l)		
		Naphthalene	Phenanthrene	Total*
1	0.5	10	10	20
2	1.5	25	5	30
3	1.0	10	undet. at 30	10
	$\bar{X}$ = 1.0			$\bar{X}$ = 20

Avg loading = 0.17 lbs/day

5. LOADING ESTIMATES FOR A CONTAMINANT GROUP WHEN ONE OR MORE MEMBERS OF THE GROUP WERE UNQUANTITATED

1	0.5	10	10	20
2	1.5	25	5	30
3	1.0	10	<15	<25
	$\bar{X}$ = 1.0			$\bar{X}$ = <25

Avg loading = 0.21 lbs/day

6. LOADING ESTIMATES FOR A CONTAMINANT GROUP WHEN ONE OR MORE MEMBERS OF THE GROUP WERE UNMEASURED

1	0.5	10	10	20
2	1.5	11	not measured	11
3	1.0	15	5	20
	$\bar{X}$ = 1.0			$\bar{X}$ = 17

Avg loading = 0.14 lbs/day

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*Concentrations of many compounds were summed to obtain the total polycyclic aromatic hydrocarbon (PAH) concentration though only two are shown here to simplify the presentation.

Figure 2.10. Examples of procedures used in calculating average discharge loads.

- Undetected Values: Undetected values were not used in calculating average concentrations and loadings. It was necessary to exclude these observations because of the extreme variation in detection limits among the surveys included in the Commencement Bay database. The example in Figure 2.10 (Case 2) is typical of the range of detection limits found in the database. Chemical analyses of a particular discharge that were characterized by high detection limits are so noted in Section 7 (Source Evaluation), since the discharge could be a significant but unquantified contaminant source.

- Detected but Unquantitated Concentrations for Single Compounds: If a contaminant concentration exceeded a detection limit but was less than a quantitation limit, it was reported in the database as less than the quantitation limit. Such values were included when calculating an average concentration or loading since it is reasonable to assume that the actual concentration may be at least half the quantitation limit.

- Loading Estimates for a Contaminant Group When One or More Members of the Group Were Undetected: See Undetected Values, above. The total group concentration does not include undetected values, but only measured concentrations or "less than" values.

- Loading Estimates for a Contaminant Group When One or More Members of the Group Were Unquantitated: When the concentration of one or more members of a contaminant group were detected but unquantitated ("less than" value), the quantitation limits of those members were included in the total group concentration. The group concentration was then reported as less than a specified value.

- Loading Estimates for Contaminant Group When One or More Members of the Group Were Unmeasured: When the concentration of a contaminant group in a discharge was determined (e.g., total chlorinated butadienes, total PAH), the individual compounds included in the group sum may have varied from survey to survey. Analyses in which more compounds of the group were measured will yield higher loading estimates than analyses in which fewer compounds were measured. In practice, however, the actual bias was minimal. Since regulatory agencies typically test for an established suite of compounds (i.e., priority pollutants), there were relatively few instances in the database when all surveys did not consistently measure the same suite of contaminants within a group. For the few instances when such inconsistencies did occur, effects on the calculated loading were noted in the test.

Source loading data for Commencement Bay are of limited and uneven quality. This factor often constrained the conclusions concerning potential sources.

2.12.3.2 Average Mass Flux Estimates--

After initial identification of probable sources of a contaminant, a review was performed to determine if the suspected contaminant inputs adequately accounted for the observed levels of contamination. This determination was made using a mass flux approach as a first approximation only. These calculations are not used to develop a mass balance for contaminants in Commencement Bay. Limitations to the use of this approach in data interpretation are summarized below after the following discussion of conceptual terms.

If the mass of sediment deposited over a given waterway within a given time period can be established, then the mass of contaminant deposited within this area can also be estimated. The time frame to achieve a given average contaminant concentration can also be estimated. The concentration of a contaminant in surficial sediments can be expressed as:

$$\text{Contaminant Concentration} = \frac{\text{Contaminant flux to the sediment surface}}{\text{Sediment flux to the sediment surface}}$$

Rearranging the expression and including appropriate units yields:

$$\text{Contaminant Flux } (\text{mg}\cdot\text{cm}^{-2}\cdot\text{yr}^{-1}) = \text{Concentration (mg/kg)} \times \text{Sediment Flux } (\text{mg}\cdot\text{cm}^{-2}\cdot\text{yr}^{-1}) \times 10^{-6} \text{ kg/mg}$$

Sediment flux was the most difficult to quantify but was estimated from the work of Carpenter et al. (1985) in which flux was estimated for 44 core samples taken throughout Puget Sound. Values ranged from 46 to 1,200 $\text{mg}\cdot\text{cm}^{-2}\cdot\text{yr}^{-1}$ with an average of 336 $\text{mg}\cdot\text{cm}^{-2}\cdot\text{yr}^{-1}$. Sediment accumulation rates in Commencement Bay waterways can be higher than those in the main body of Puget Sound, because of higher inputs of terrestrial-derived particulates. Despite this limitation, the maximum sediment flux observed in the sound by Carpenter et al. (1985) (1,200 $\text{mg}\cdot\text{cm}^{-2}\cdot\text{yr}^{-1}$) was used to provide an order-of-magnitude estimate of actual sediment flux in the waterways.

Substituting 1,200 $\text{mg}\cdot\text{cm}^{-2}\cdot\text{yr}^{-1}$ in the equation above yields:

$$\text{Contaminant Flux } (\text{mg}\cdot\text{cm}^{-2}\cdot\text{yr}^{-1}) = \text{Concentration (mg/kg)} \times 0.0012 \text{ kg}\cdot\text{cm}^{-2}\cdot\text{yr}^{-1}$$

This average contaminant flux is the mass of contaminant that would have to be introduced to the waterway to achieve the observed average level of sediment contamination, assuming no advection into or out of the system. It is referred to hereafter as the concentration-derived mass flux. No assumptions were made regarding the actual distribution of the deposited material in the waterway; the calculations reflect the overall average estimated flux only.

An average contaminant flux based on known loadings of the contaminant, referred to hereafter as the source-derived mass flux, can be estimated if the surface area over which the contaminant is deposited is known:

$$\text{Contaminant Flux } (\text{mg}\cdot\text{cm}^{-2}\cdot\text{yr}^{-1}) = \frac{\text{Loading (lb/day)} \times 1.65\text{x}10^{8}}{\text{Surface area of deposition } (\text{cm}^{2})}$$

where 1.65×10^{8} is a coefficient to convert lb to mg and days to years.

If it is assumed that the contaminant is deposited in sediments throughout the waterway, the waterway surface area can be used in the expression. The surface areas used in these calculations were: Hylebos Waterway, 1.0×10^{10} cm^2; Sitcum Waterway, 1.6×10^9 cm^2; St. Paul Waterway, 1.8×10^9 cm^2; Middle Waterway, 9.8×10^8 cm^2; and City Waterway, 4.5×10^9 cm^2. No assumptions were made regarding the actual depositional pattern of the contaminant within these areas.

The average contaminant concentration in the waterway was determined and used to calculate a concentration-derived mass flux (i.e., the mass of the contaminant that would have to be deposited in the waterway in a given time period to attain the observed average concentration). The sum of known source loadings for the contaminant was then determined and used to calculate a source-derived mass flux (i.e., the mass of contaminant estimated to be entering the waterway from identified sources).

Large uncertainties are associated with source loading data and estimated sediment accumulation rates for the nearshore/tideflats area of Commencement Bay. Therefore, the mass flux approach was used only to evaluate data gaps in source loading information (i.e., whether major sources were unaccounted for when the source-derived mass flux of contaminants was compared with the average concentration-derived mass flux). The criteria used to determine these potential data gaps were as follows:

- When the source-derived mass flux was at least two orders of magnitude lower than (i.e., less than 1 percent of) the sediment concentration-derived mass flux, the contaminant was considered to have major unidentified sources. The conclusion that major sources remained unidentified was made on the basis of mass flux estimates only if this condition was met. Even given the uncertainties of the analysis, this conclusion is warranted because it identifies a potential data gap.

- When the source-derived mass flux value was within two orders of magnitude of the value for the sediment concentration-derived mass flux, the two values were considered comparable given the uncertainties of the analysis. No conclusions concerning sources were made.

- When the source-derived mass flux value exceeded the sediment concentration-derived mass flux by more than two orders of magnitude, the two values were still considered comparable within the uncertainty of the analysis. It might have been inferred that the identified sources more than accounted for the observed contamination, but sediment accumulation rates might have been underestimated and source contributions might have been overestimated. Hence, no conclusions concerning sources were made.

Although the calculations and comparisons discussed in this section were made for all available data, only the final results are summarized in the source evaluation section of this report. If a contaminant was undetected in all available source data sets, no attempt was made to determine mass flux estimates for that contaminant.

2.12.3.3 Reference Numbers--

All point source and runoff discharges to the study area for which loading data exist, as well as some groundwater seeps, were identified in Section 7 (Source Evaluation) by a five-character reference number (e.g., HK-052). These reference numbers were developed by the Tacoma-Pierce County Health Department during drainage system investigations in which an attempt was made to locate every seep, ditch, and drain within the nearshore/tideflats area (Rogers et al. 1983). The reference system was expanded as part of the present investigation to include additional discharges. Throughout the text, each discharge is identified by its reference number and, if available, a common name (e.g., HM-028 = Morningside Ditch) or descriptor (e.g., HY-018 = 8-in steep pipe). A corresponding map of each waterway is also provided.

2.12.4 Groundwater Sources

There is evidence of groundwater contamination within many portions of the nearshore/tideflats area because of past spills, use of unlined industrial waste ponds, and landfilling of hazardous materials. Dames and Moore (1982) listed over 30 sites where past practices could be adversely affecting groundwater quality. However, as noted by Tetra Tech (1984b), adequate assessment of groundwater contamination is hampered by the absence of reliable groundwater flow information throughout most of the tideflats. Existing data are inadequate to determine the magnitude of groundwater contamination, predict the route of groundwater flow from a contaminated area, or determine the loading of contaminants to the waterways via groundwater.

Local, state, and federal agencies were contacted to obtain all available well log data for information on groundwater flow, including the Port of Tacoma, Tacoma Public Utilities Department, Pierce County Department of Public Works, State Department of Highways, WDOE, and the U.S. Geological Survey. From these inquiries, it became apparent that little well log data exist for the tideflats west of the I-5 corridor. The existing data are spatially limited to selected properties investigated specifically to assess the extent of groundwater contamination. These properties include:

- Occidental Chemical Corporation
- Three Occidental waste disposal sites (General Metals, Dauphin, Petarcik)
- Pennwalt Corporation
- Kaiser Aluminum
- Allied Chemicals
- Georgia Pacific
- D Street Petroleum Storage Area

- Chemical Processors/Lilyblad Petroleum
- Tar Pits site
- Tacoma Spur
- Union Pacific Railroad yard
- Two U.S. Gypsum waste disposal sites.

These data were used in source identification when appropriate. For many of these sites, the data were of limited utility because of inadequacies in sampling and/or analytical methodology.

2.12.5 Atmospheric Sources

Available data from the Puget Sound Air Pollution Control Agency (PSAPCA) and the U.S. EPA Air Work Group were examined to evaluate atmospheric source emissions in the Tacoma area. Relevant information was scarce. PSAPCA typically monitors total suspended particulate matter, sulfur oxides, nitrogen oxides, volatile organic compounds, and carbon monoxide. Very little data are available from either PSAPCA or U.S. EPA concerning the priority pollutants and other contaminants identified to be of concern in the current investigations. Limited metals data were available from the high-volume filters maintained around the Tacoma area by PSAPCA. These instruments are designed to collect the small suspended particulates that would travel far from the Tacoma area prior to deposition. Corresponding data do not reflect the contaminant input potentially resulting from large particulates that would be expected to enter the waterways directly from local industrial fallout or through stormwater runoff (Nolan, J., personal communication).

2.12.6 Spills

Files of both the U.S. Coast Guard (USCG) and WDOE were reviewed to obtain information on past spills of hazardous materials in the nearshore/tideflats area. The USCG files were not useful in providing the type of data required because of imprecision in reporting the spill location (i.e., to the nearest minute latitude and longitude). For example, a spill occurring at 47° 16' N latitude and 122° 26' W longitude could have occurred in the Puyallup River; St. Paul, Middle, or City Waterway; or the southeast portion of Commencement Bay.

WDOE Environmental Complaint fields from 1979 to 1985 were also reviewed. Within this 5-yr period, WDOE received reports of approximately 30 hazardous material spills that could affect environmental quality in the waterways or along the Ruston-Pt. Defiance Shoreline. Sulfuric acid spills (mostly from ASARCO) constituted approximately one-third of this total. The remainder included spills of plating wastes, paint, solvents, caustic, creosote, fungicide, and sodium chlorate. In addition, about 35 petroleum spills in excess of 50 gal occurred in the nearshore/tideflats during this same period.

Additional spill-related information was obtained from WDOE files on specific industries. For areas of elevated sediment concentrations, files were reviewed of all nearby industries that might handle products containing the contaminant of concern. This file review uncovered many additional spills not included in the Environmental Complaint files.

2.12.7 Dredging

The dredging history of the Nearshore/Tideflats area was reviewed to help interpret horizontal and vertical contamination gradients observed in the sediment core samples. Maintenance dredging activities were reviewed and summarized in Dames and Moore (1981, 1982). Information on private dredging activities within the nearshore/tideflats area was obtained by a WDOE review of U.S. Army Corps of Engineers (COE) and U.S. EPA files. All dredge and fill applications submitted to the COE from 1972 to the present were reviewed to identify the industrial applicant, the spatial extent of dredging activities, and the volume of material intended for removal. Since COE records did not indicate whether the intended dredging actually occurred or how much of the material permitted for removal was actually removed, this information was obtained from U.S. EPA staff (Duane Karna) or by phone calls to the applicants.

3.0 RESULTS

3.1 SEDIMENT CHEMISTRY

The following sections provide a summary of chemical results for over 190 surface and subsurface samples of subtidal sediments collected from Commencement Bay as part of the 1984 Superfund investigation. An additional six sediment samples were collected from Carr Inlet reference stations for complete chemical characterization. These data include blank-corrected analyses for the 13 U.S. EPA priority pollutant metals, 3 additional metals (including iron and manganese used as natural indicators), 78 extractable U.S. EPA priority pollutant compounds, 12 additional U.S. EPA Hazardous Substance List compounds, and selected tentatively identified compounds for which all samples were analyzed. Twenty of the samples were also analyzed for the 31 U.S. EPA volatile priority pollutants and/or 2,3,7,8-tetrachlorodibenzodioxin. The focus of these sections is to:

- Provide a chemical perspective of Commencment Bay study areas, including the general distributions, concentration ranges, and frequencies of detection of chemical contaminants

- Define groups of chemicals with similar spatial distributions in Commencement Bay sediments and/or with similar chemical characteristics

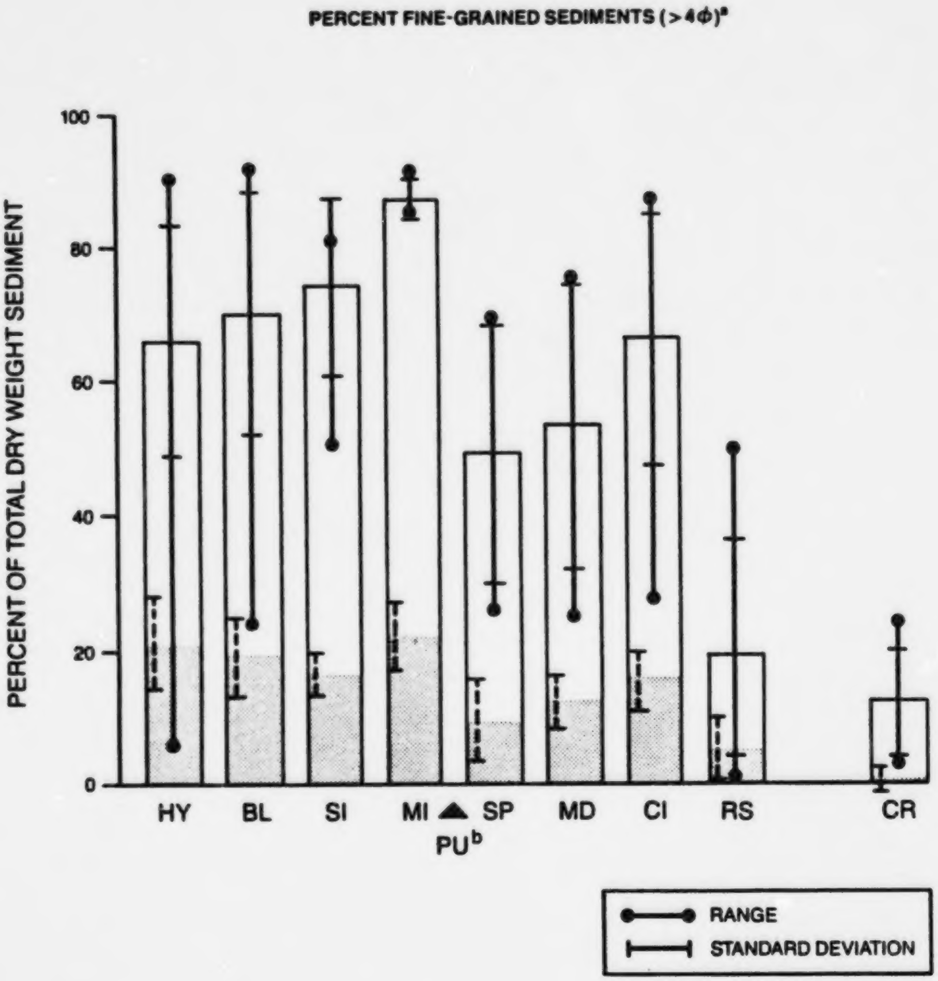
- Determine the magnitude of contamination relative to conditions at Carr Inlet reference areas, and the significance of this contamination relative to conditions at all Puget Sound reference areas

- Condense the list of chemicals of concern to those detected in Commencement Bay study area sediments at levels that exceed Puget Sound reference area conditions

- Provide a summary list of Commencement Bay study areas, segments within areas, and individual stations with the highest levels of contamination for each chemical of concern.

3.1.1 Bulk Sediment Characteristics

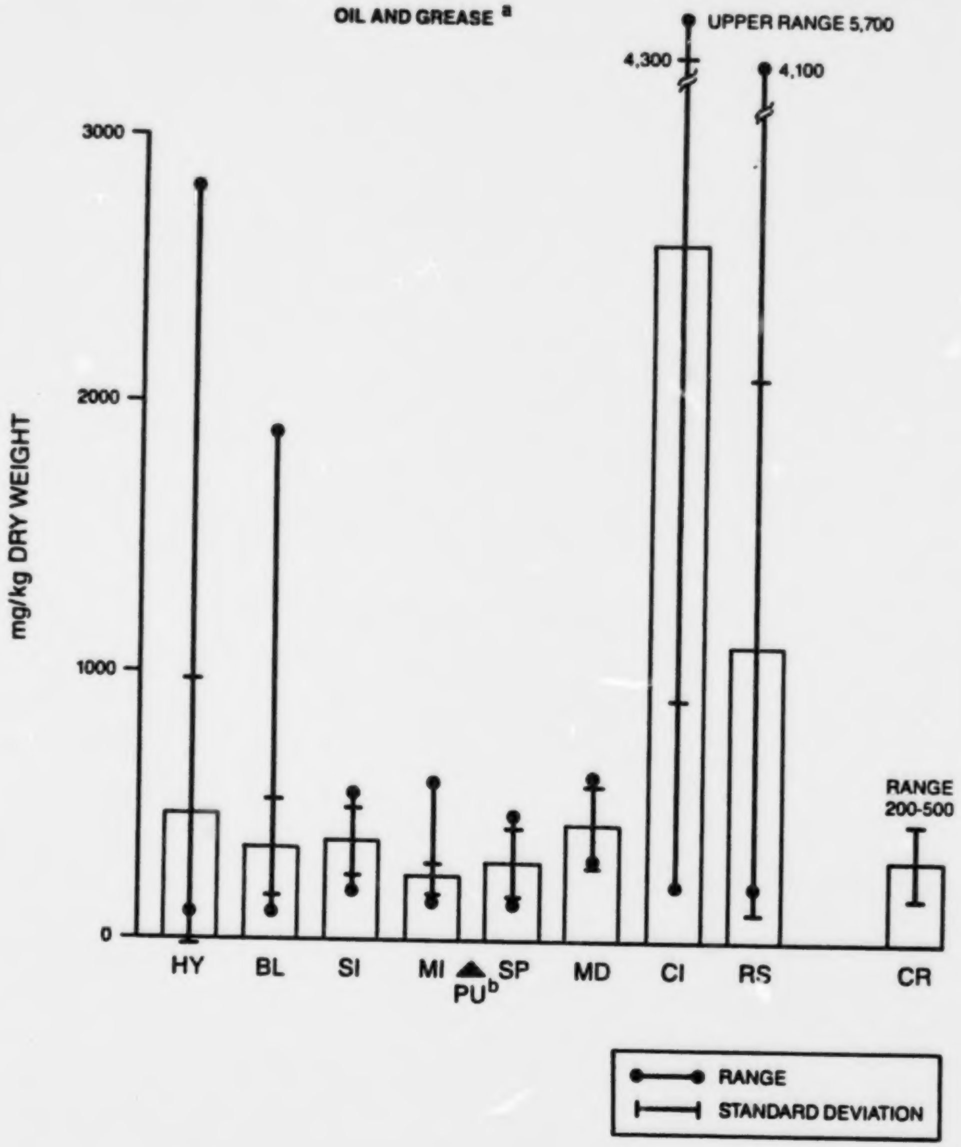
Conventional analyses of bulk sediments included determination of the grain size distribution, and concentrations of oil and grease, volatile solids, total organic carbon, nitrogen, and sulfides. Results of these analyses are summarized in Figures 3.1-3.5. Original data for individual sediment samples are presented in Appendix III.



[a] SHADED AREAS INDICATE THE PERCENTAGE OF CLAYS (>8Φ); DATA ARE FROM MARCH 1984 SEDIMENT ANALYSES ONLY (n = 115)

[b] LOCATION OF PUYALLUP RIVER INDICATED BY ARROW. STUDY AREAS SHOWN GEOGRAPHICALLY FROM NORTH (LEFT) TO SOUTH (RIGHT).

Figure 3.1. Total average percent fine-grained material (>4 phi) and average percent clay (>8 phi) in sediments from Commencement Bay and Carr Inlet study areas.



[a] DATA ARE FROM MARCH 1984 SEDIMENT ANALYSES ONLY (n = 115)

[b] LOCATION OF PUYALLUP RIVER INDICATED BY ARROW. STUDY AREAS SHOWN GEOGRAPHICALLY FROM NORTH (LEFT) TO SOUTH (RIGHT).

Figure 3.2. Total average oil and grease concentrations in sediments from Commencement Bay and Carr Inlet study areas.

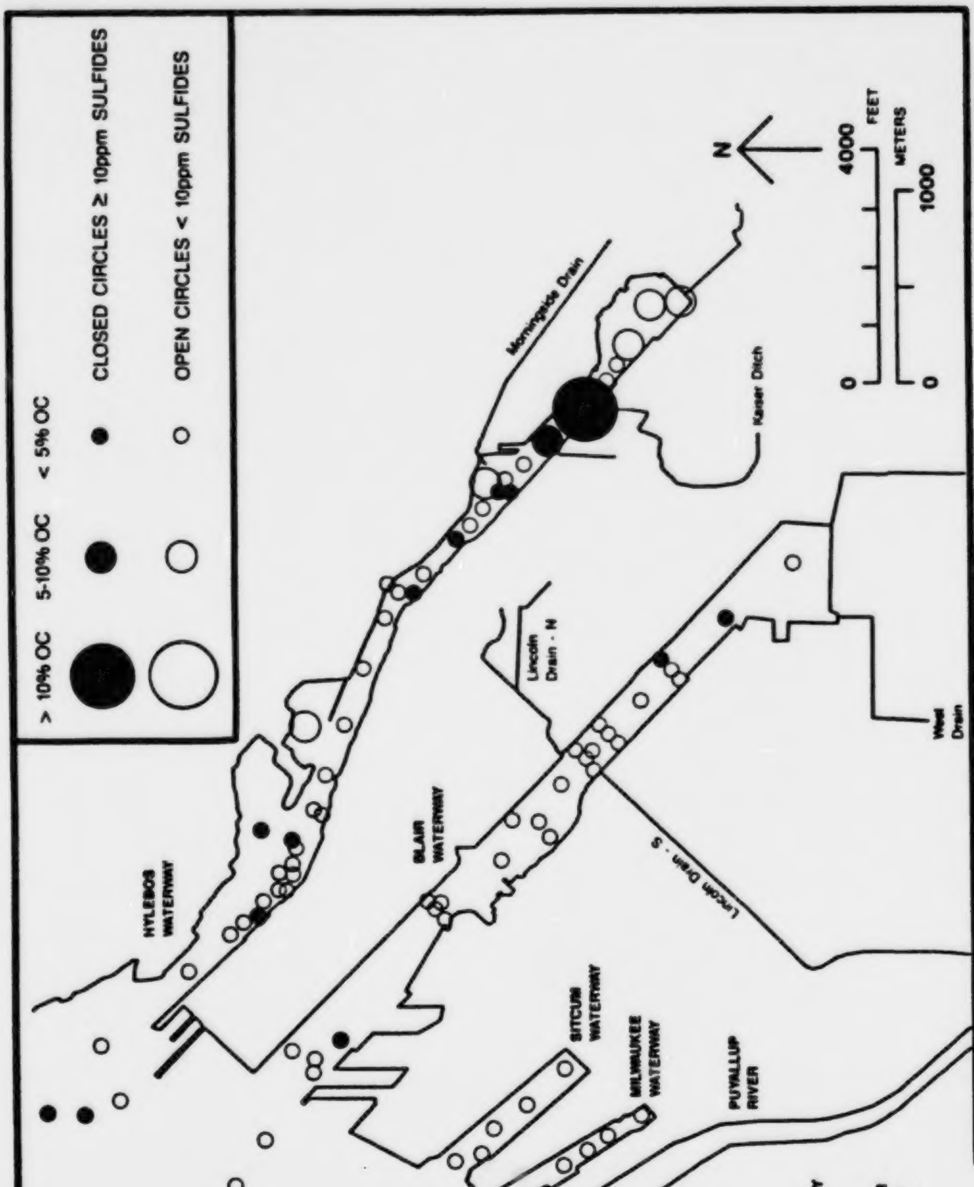

> 10% OC
5-10% OC
< 5% OC
CLOSED CIRCLES ≥ 10ppm SULFIDES
OPEN CIRCLES < 10ppm SULFIDES
COMMENCEMENT BAY
HYLEBOS WATERWAY
BLAIR WATERWAY
SITCUM WATERWAY
MILWAUKEE WATERWAY
PUYALLUP RIVER
ST. PAUL WATERWAY
MIDDLE WATERWAY
WHEELER OSGOOD
CITY WATERWAY
Morningside Drain
Kaiser Ditch
Lincoln Drain - N
Lincoln Drain - S
West Drain
N
0
4000
FEET
0
1000
METERS

Figure 3.3. Relative concentrations of sediment organic carbon and sulfides in Commencement Bay study areas (January and March, 1984).

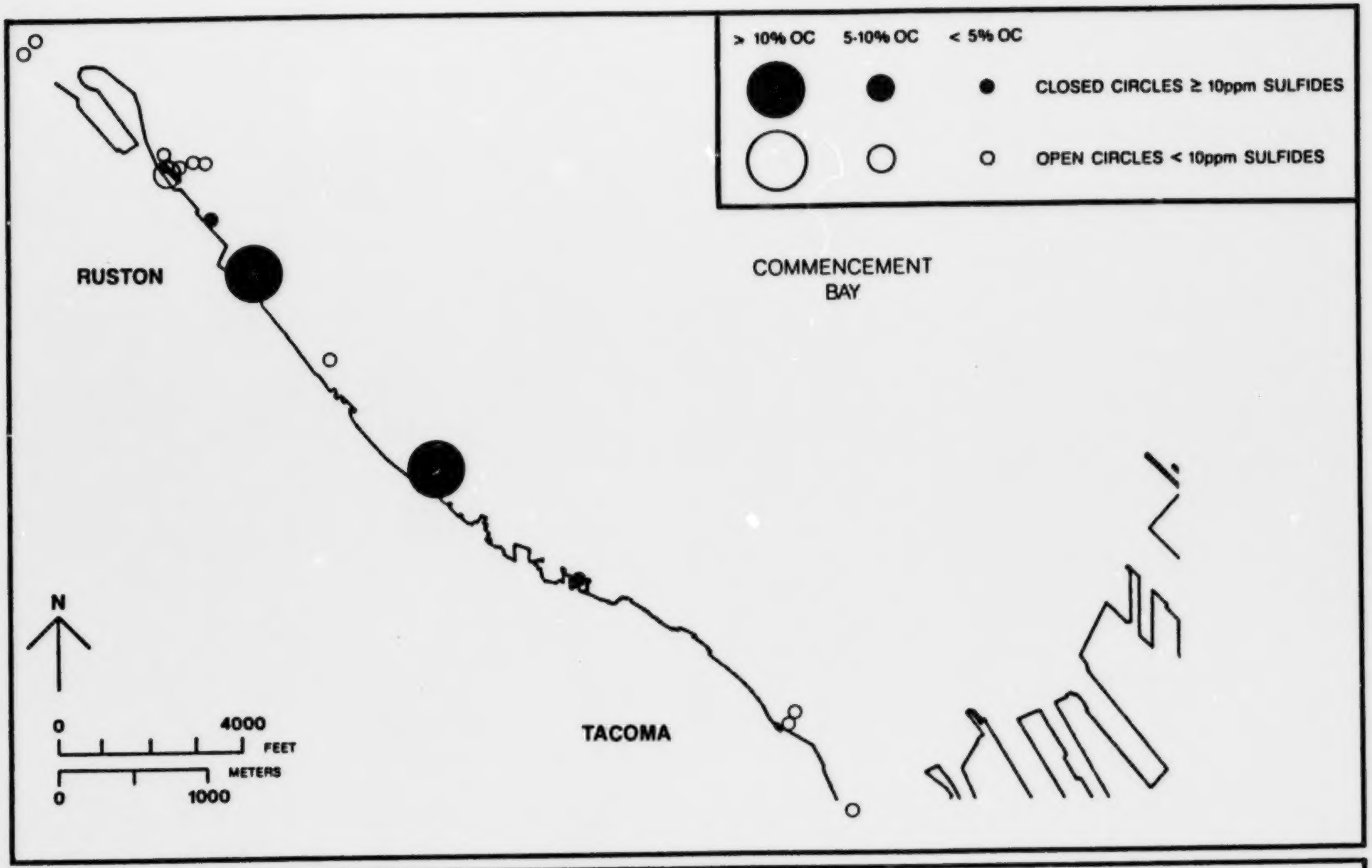

> 10% OC
5-10% OC
< 5% OC
CLOSED CIRCLES ≥ 10ppm SULFIDES
OPEN CIRCLES < 10ppm SULFIDES
COMMENCEMENT BAY
RUSTON
TACOMA
N
0
4000
FEET
METERS
0
1000

Figure 3.3. (Continued)

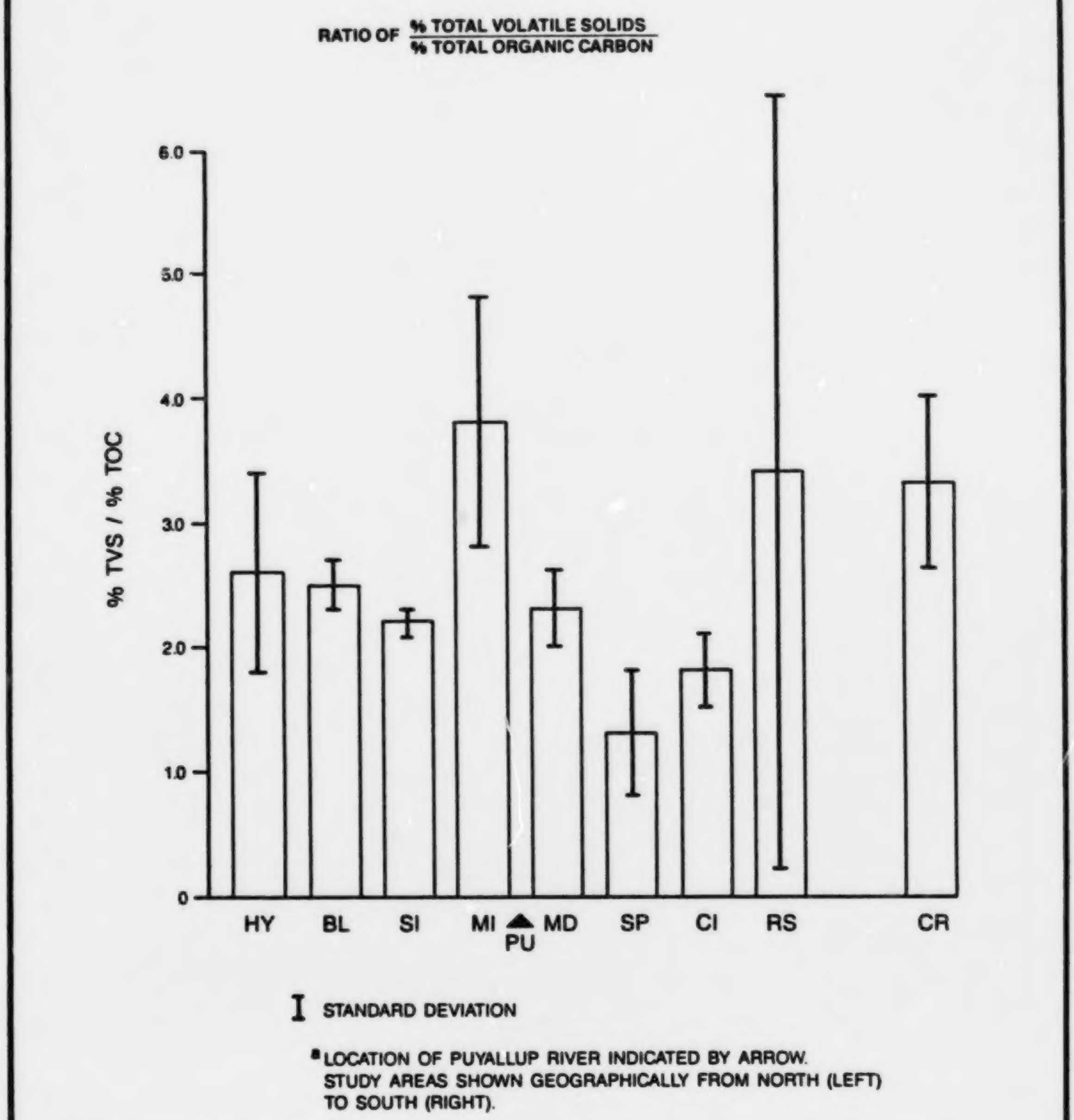
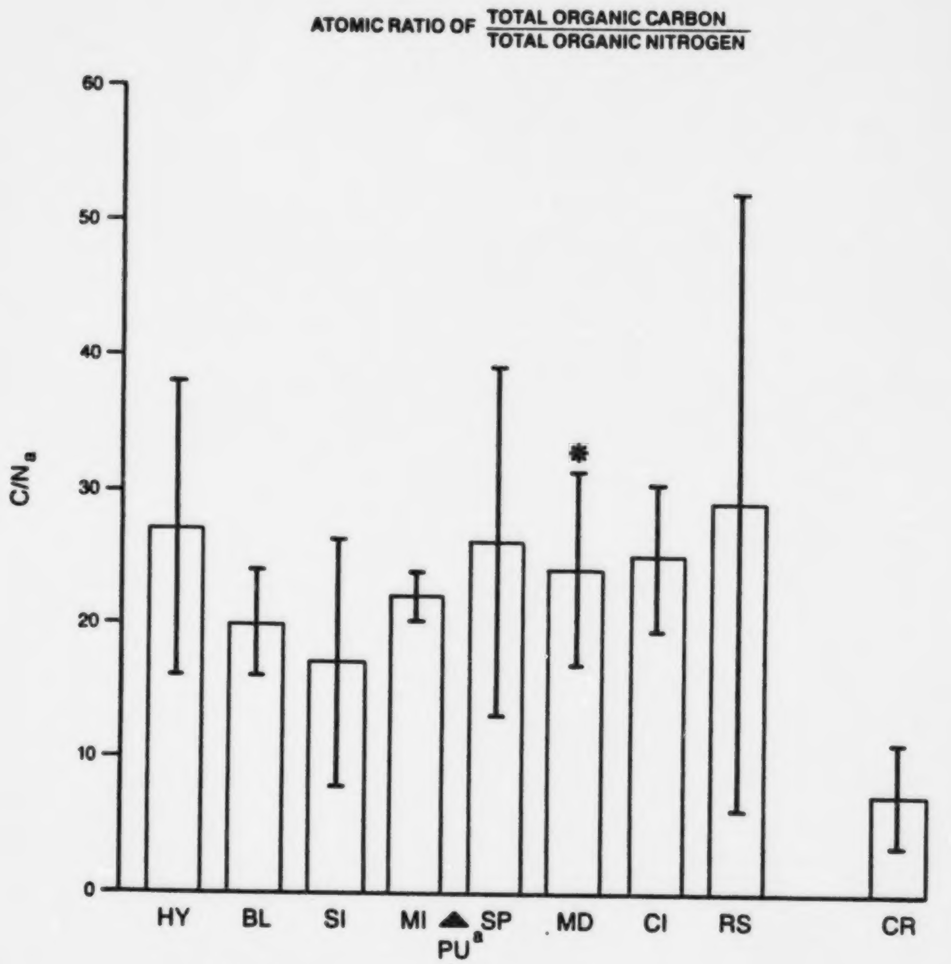


Figure 3.4. Comparison of the average percent total volatile solids with average percent total organic carbon in sediments from Commencement Bay and Carr Inlet study areas.



* EXCLUDES AN ANOMALOUSLY HIGH C/N RATIO OF 210 AT MD-13; THE AVERAGE INCLUDING THIS VALUE IS 87 ± 110.

I STANDARD DEVIATION

[a] LOCATION OF PUYALLUP RIVER INDICATED BY ARROW. STUDY AREAS SHOWN GEOGRAPHICALLY FROM NORTH (LEFT) TO SOUTH (RIGHT).

Figure 3.5. Comparison of the average atomic carbon/nitrogen ration (C/N) in sediments from Commencement Bay and Carr Inlet study areas.

3.1.1.1 Grain Size--

The average percent of fine-grained material (silt plus clay; >4 phi) and the average percent of clay (>8 phi) in sediments of each study area are displayed in Figure 3.1. The percent of fine-grained material (primarily silt) tended to decrease north of the Puyallup River. This decrease probably corresponds with a decrease in the load of silty material discharged by the Puyallup River in a predominantly northward-trending plume. Major discharges from stormwater drains at the head of City Waterway contributed to the observed accumulation of fine-grained sediments in that waterway. The range and variability in the percent of fine-grained sediments along the Ruston-Pt. Defiance Shoreline were similar to those of reference sediments from Carr Inlet. Sediments collected within Carr Inlet were substantially coarser than most sediments sampled in Commencement Bay. Effects of this difference in grain size on interpretations of chemical and biological data are discussed in later sections.

3.1.1.2 Oil and Grease--

Average oil and grease concentrations (mg/kg dry sediment) for Commencement Bay study areas are presented in Figure 3.2. Highest concentrations were found in sediments from City Waterway and along the Ruston-Pt. Defiance Shoreline. Oil and grease concentrations decreased from the head of City Waterway to the mouth, suggesting a substantial contribution from drains at the head of the waterway. Changes in the spatial distribution of oil and grease concentrations along the Ruston-Pt. Defiance Shoreline suggest multiple local sources. The highest dry-weight (DW) values were found at Station RS-18 (4,100 mg/kg) off the main ASARCO plant outfall and at Station RS-16 (2,100 mg/kg) along the shoreline (see Figures 2.1-2.3 for station locations). Average oil and grease sediment concentrations in other study areas were comparable to those measured at Carr Inlet.

3.1.1.3 Total Organic Carbon and Sulfides--

The extent of organic enrichment in Commencement Bay surface sediments, as indicated by the percent total organic carbon (TOC) content, is summarized in Figure 3.3. Measured TOC sediment values ranged from <1 percent at several stations to 20.5 percent at Station RS-16 along the Ruston-Pt. Defiance Shoreline. Sediments in the isolated Wheeler-Osgood branch of City Waterway were also highly enriched (18 percent TOC). TOC levels in the remainder of City Waterway sediments consistently declined from 8.9 percent at the head of the waterway to 1.2 percent at the mouth. Other study areas having major variations in TOC content included St. Paul Waterway (TOC range 1.5-16 percent), and Hylebos Waterway (TOC range 0.26-12 percent).

Sediment sulfide concentrations are summarized in Figure 3.3 in relationship to the observed TOC concentrations. Concentrations of free sulfides in Commencement Bay surface sediments indicated in Figure 3.3 were classified as either <10 or ≥10 mg/kg DW. This general classification of sediments into groups of "low" and "high" sulfide content takes into account uncertainty in analytical results for most of the sulfide analyses performed (see preservation discussion in Methods, Section 2.2). The sulfide values reported for samples collected in March, 1984 are considered minimum estimates of in situ concentrations. Maximum sulfide levels were reported for preserved sediments collected during January, 1984 and ranged up to 710 mg/kg DW at Station CI-02.

All Commencement Bay sediments with substantial organic enrichment (i.e., >10 percent TOC) also contained sulfides $\geq$10 mg/kg DW, as did most sediments with moderate organic enrichment (i.e., 5-10 percent TOC). Low concentrations of sulfides (i.e., <10 mg/kg DW) were measured in most Commencement Bay sediments with low organic enrichment (i.e., <5 percent TOC). Reference sediments from Carr Inlet contained <6 mg/kg sulfides and <0.3 percent TOC.

High-sulfide sediments were found throughout the organically enriched City Waterway, except at two stations at the mouth of the waterway (Figure 3.3), where TOC levels measured <3 percent. Sediments collected from all stations within the adjacent Middle Waterway contained high sulfides, as did sediments from the organically enriched Station SP-14 in St. Paul Waterway off the main Champion International paper mill outfall. Low-sulfide sediments were found at all other St. Paul Waterway stations and at all stations from Milwaukee and Sitcum Waterways. Low sulfide concentrations in these sediments coincided with relatively low TOC concentrations, an apparent common characteristic of stations near the mouth of the Puyallup River. With some exceptions, low sulfide levels were also found throughout Blair Waterway, where TOC averaged <1.5 percent.

Sediment sulfide concentrations in upper Hylebos Waterway were high in the organically enriched sediments off the Kaiser Ditch. Moderately organically enriched sediments in the upper turning basin of Hylebos Waterway off Hylebos Creek had consistently low sulfide concentrations. Sulfide concentrations >10 mg/kg DW were found in several sediment samples collected near major outfalls along Hylebos Waterway, and in some samples collected outside the waterway mouth; most of these samples contained <5 percent TOC.

3.1.1.4 Total Volatile Solids (TVS)--

TVS measurements are often used instead of TOC measurements as a relatively inexpensive means of testing for organic enrichment. TVS is determined by the difference in the total weight of a sediment sample before and after heating at $\geq$550° C. This technique is less precise than the quantitative determination of TOC in a sample by combustion, and can overestimate the actual organic load because of simultaneous volatilization of inorganic sediment components with organic carbon and non-carbon organic material. The amount of volatilized inorganic components will vary among sediments.

Despite these potential limitations, a strong correlation was found in the overall distribution of percent TVS with percent TOC in sediments from Commencement Bay and Carr Inlet. The linear regression equation determined for these data is:

$$\mathrm{TOC} = -0.346 + 0.5051(\mathrm{TVS}) \qquad r^2 = 0.81,\ n=144$$

The regression predicts that TOC is approximately half the observed TVS value, or that TVS overestimates TOC by approximately a factor of two. The variability in the average ratio of percent TVS to TOC among Commencement

Bay study areas is demonstrated in Figure 3.4. The greatest variability in this ratio, approaching 100 percent, was found for sediments from the Ruston-Pt. Defiance Shoreline. The average ratio varied among study areas by a factor of approximately three. There was no consistent trend among study areas between TVS/TOC variation and grain size differences shown in Figure 3.1, although a high average ratio of TVS to TOC was observed for coarse sediments from the Ruston-Pt. Defiance Shoreline and from Carr Inlet. TVS/TOC ratios exceeding an order of magnitude were found at two stations: HY-46 in lower Hylebos Waterway and RS-13 along the Ruston-Pt. Defiance Shoreline (ratio of 15 and 13, respectively).

The overall strong correlation of TVS with TOC observed for Commencement Bay and Carr Inlet sediments suggests that TVS is a valuable indicator of organic enrichment for general purposes. Because of the range and variability in the ratio of TVS to TOC among sediments, direct measurements of TOC are used in this report when calculating chemical concentrations normalized to sediment organic content for use in source and biological effects evaluations (see discussion below in Section 3.1.2).

3.1.1.5 Total Organic Carbon/Nitrogen Ratios (C/N)--

The average ratio of carbon to nitrogen (C/N) for study area sediments, after correction for differences in the atomic weight of the two molecules, is given in Figure 3.5. Elevated sediment C/N ratios, which provide evidence that carbon-rich materials have been incorporated into the sediments, have been used as a general indicator of sediment contamination. Examples of sources of this material in urban discharges include coals, oils, and paper products. Sewage effluents contain substantial loads of carbon-rich material (e.g., cellulose), but are also nitrogen-rich. Therefore, although an elevated C/N ratio is indicative of contamination, a lower C/N ratio is not proof that a sediment is contaminant-free.

The observed average atomic C/N ratio for Carr Inlet sediments (i.e., 8.5) is typical of marine sediments. The average atomic C/N ratio for sediments in all Commencement Bay study areas is substantially higher than reference. These data suggest that carbon-rich materials have accumulated over most of the Commencement Bay area. This is true even for sediments from some stations located outside of the mouths of Hylebos and Blair Waterways, where atomic C/N ratios ranged from 1.3 to 20. Aside from local discharges, a source of carbon-rich material in Commencement Bay sediments is accumulations of Puyallup River particulate material, which likely contains coal fragments eroded from upriver deposits (Barrick et al. 1984).

3.1.2 Normalization of Chemical Concentrations

In this report, chemical data are used to:

- Determine the relative magnitude of contamination among Commencement Bay areas and in comparison with reference conditions at Carr Inlet

- Define areas with problem sediments, where sediment toxicity or biological effects are shown to occur above some threshold concentration of a chemical in sediments

- Evaluate spatial and temporal distributions of contaminants when tracing potential sources of contamination (heavily contaminated areas will be prioritized for possible source control even if no clear relationship to observed sediment toxicity or biological effects has been established).

To accomplish these objectives, chemical data must be normalized to account for physical and physicochemical differences among samples. Otherwise, these differences may mask potential trends in chemical concentrations that would be useful in interpreting environmental data. Sediment chemical concentrations in this report are expressed in three possible ways, as appropriate: the mass of a chemical relative to (1) total sediment dry-weight, (2) total weight of the fine-grained sediment fraction, or (3) total weight of sediment organic carbon. These normalizations are based on observed and theoretical factors known to affect the quantity of chemicals in a given volume of sediment:

1. Most sediment contaminants are associated primarily with the solid material in bulk sediments, not with the interstitial water. Because the percent water content can vary considerably among samples, wet-weight concentrations are typically poor indicators of the relative quantity of chemicals among samples.

2. Fine-grained sediments naturally tend to accumulate more chemicals than coarse-grained sediments because the relative surface area available for adsorption of chemicals increases with decreasing grain size.

3. Many trace chemicals are associated and transported with organic carbon-rich particles in the environment, or can be bound by organic carbon in sediments. Carbon-rich sediments tend to contain a larger quantity of these chemicals than carbon-poor sediments.

The first major use of chemical data in this report is to evaluate the relative magnitude of contamination among Commencement Bay areas. Dry-weight concentrations were selected for this evaluation. Changes in dry-weight concentrations reflect proportional changes in the relative quantity of chemicals at different sites because the bulk dry density of sediment is nearly constant at approximately 2.5 g/cm^3 (in situ; Robbins and Edgington 1975), regardless of variations in the grain size distribution. For example, 10 mg of copper measured in a sample containing 80 percent sand would yield approximately the same dry-weight concentration as 10 mg of copper measured in an equal volume of sample containing 80 percent clay. The magnitude of error associated with the assumption of equal density among Commencement Bay sediments is probably less than 50 percent, given the natural variability in densities of common expandable clays (e.g., montmorillinite) and differences in densities attributable to enrichment of slag particles, for example, in some bulk sediments.

A comparison of contamination among Commencement Bay sites with reference conditions at Carr Inlet is also made on a dry-weight basis in later sections. Data presented in Figure 3.1 indicate that much coarser sediments are found in Carr Inlet than in most of Commencement Bay. For the reasons just stated, comparisons of dry-weight concentrations between the two areas provide a reasonable estimate of the relative mass of contaminants in fine-grained Commencement Bay sediments compared with those in the coarse-grained sediments at Carr Inlet. Differences in average grain size distributions are relevant in interpreting the significance of observed elevations in dry-weight concentrations. Because of the lower capacity of sandy sediments to accumulate and transport pollutants relative to fine-grained sediments, elevated contaminant levels within sandy sediments would not be expected, except at sites directly adjacent to a contaminant discharge. The meaning of a "significant" elevation above reference for dry-weight concentrations is presented in Section 3.1.3 (Sediment Metals) and Section 3.1.4 (Sediment Organic Compounds).

The second major use of chemical data in this report is to evaluate relationships among chemical concentrations, sediment toxicity, and biological effects to help define action levels. Only a small portion of the total amount of a contaminant may be bioavailable (i.e., available for direct contact with organisms either through surface contact, respiration, or ingestion). The bioavailable portion of the total contaminant mass may also vary among sediments. Hence, measurements of the total sediment concentration of a chemical may not correspond with changes in observed toxicity or biological effects among different sediment samples. Sediment matrix effects that alter the bioavailability of contaminants include adsorption of chemicals onto sediment surfaces and absorption into sediment matrices [e.g., fecal pellets (Karickhoff and Morris 1985), humic substances, or clay lattices]. An increase in organic carbon content, sediment surface area, or expandable clay content may result in contaminants being bound to particles in such a way that the bioavailability of the contaminant is reduced.

For example, a coarse-grained sediment with a low dry-weight concentration of a toxic contaminant and a fine-grained, organic-rich sediment with a high dry-weight contaminant concentration may exhibit similar toxicity. When normalized to organic carbon or percent fine-grained material, the resulting normalized concentrations may be similar, thus supporting the observed similarity in toxicity. This situation would suggest that similar available or effective amounts of a contaminant were present in the two dissimilar bulk sediment samples. The bioavailability question may be resolved by direct measurements of contaminant concentrations associated with different sedimentary components (e.g., interstitial water, or a specific size or density fraction of the sediment). These tests were beyond the scope of the present study. Therefore, the approach here is to examine whether increases in observed toxicity or biological effects correspond with increased contaminant concentrations of metals and/or organic compounds after normalization to organic carbon or percent fine-grained material.

The third major use of chemical data in this report is to identify potential sources of contamination. For organic compounds, these source identifications make use of trends in sediment concentrations normalized to dry weight and to total organic carbon content. Interpretation of trends in metal concentrations are based on dry weight and normalizations to the total weight of the fine-grained sediment fraction (>4 phi). Inorganic and organic chemicals from pollution sources tend to be selectively enriched in sediment particulate fractions having a high content of hydrous manganese or iron oxides, high surface area, high organic carbon content, or low density (e.g., Lerman 1979; Thompson and Eglinton 1978; Karickhoff et al. 1979; Prahl and Carpenter 1983). Dilution of chemically enriched sediment fractions with variable amounts of unrelated material during transport and deposition can distort spatial trends when interpreted on the basis of dry-weight concentrations. Organic carbon or fine-grained sediment normalizations are used primarily to factor out this variability in bulk sediments when patterns in dry-weight concentrations are not apparent. When a clear gradient in dry-weight concentrations is apparent, further normalizations of chemical concentrations may be unnecessary to trace potential sources. In these cases, organic carbon or fine-grained sediment normalizations can be used to establish whether the major carbon or fine-grained sediment source in the area coincides with the source of contaminants. For example, a strong gradient in dry-weight concentrations that disappears after normalization to organic carbon suggests that the pollutant source is also a major source of organic carbon. The actual loading of contaminants on the organic carbon may be no different than that in some other area with lower dry-weight concentrations. Alternatively, a strong gradient in dry-weight concentrations that reverses or intensifies after normalization to organic carbon suggests that the discharge contributes to increased loadings of contaminants on the sedimentary organic carbon derived from a separate source.

No single concentration normalization is used in this report to the exclusion of others that may offer complementary information. Because organic carbon or fine-grained material in sediments have a finite capacity to bind contaminants and potentially reduce their bioavailability, sediments that are highly contaminated based on dry-weight and other normalizations are of greatest concern. Conversely, sediments with low contamination regardless of the normalization used are of lowest concern.

3.1.3 Sediment Metals

3.1.3.1 Surface Sediments--

Ranges in concentrations (dry weight, DW) of 16 elements in surface subtidal sediments from Commencement Bay and Carr Inlet are shown in Table 3.1. These elements include the 13 U.S. EPA priority pollutant metals. Three of these "metals" (antimony, arsenic, and selenium) are classified as metalloids, which are elements that do not strictly occur as metals in the environment. Following U.S. EPA convention and for ease of discussion, all of these elements will be referred to as metals.

The results include data for two 1984 sediment surveys conducted as part of the Superfund investigation. Additional data are included from 1984 for the Blair Waterway Dredging Survey conducted as a combined effort between the Port of Tacoma and this Commencement Bay Superfund project. In addition to the U.S. EPA priority pollutant metals, distributions of iron and manganese were determined to enable a comparison of levels of predominantly naturally derived metals among stations. Iron and manganese also form oxides that are important scavengers affecting the distribution of other metals. Barium concentrations were measured to evaluate if EP (Extraction Procedure) toxicity tests for barium would be required for sediments potentially requiring disposal as hazardous waste.

Most metals were detected in all samples. Highest concentrations of metals were found along the Ruston-Pt. Defiance Shoreline. The distributions of metals that were frequently detected over a range of concentrations or that were found in high concentration at a few sites are discussed in Section 3.1.5. The remaining metals (i.e., selenium, thallium) were either undetected at the detection limits stated in Table 3.1, or were rarely found in high dry-weight concentrations (i.e., beryllium, sliver). Their distributions are summarized in this section and these metals will not be discussed further.

Beryllium was detected at most sites, but its distribution was relatively uniform and concentrations did not exceed 0.6 mg/kg DW. Highest beryllium concentrations were found in Hylebos Waterway and near the major outfalls of the ASARCO plant on the Ruston-Pt. Defiance Shoreline. Selenium and thallium concentrations in sediments sampled directly off the major outfalls of the ASARCO plant were elevated over an order of magnitude above typical Commencement Bay levels. Selenium was undetected at all other sites and thallium was not present at more than twice its detection limit (0.05 mg/kg DW) at any other site. Silver concentrations did not exceed 0.6 mg/kg DW, except in sediments collected in January, 1984 from two City Waterway stations (CI-02, CI-03) where concentrations exceeded 2 mg/kg DW. Subsequent sampling at nearby stations in March, 1984 did not show similar levels.

3.1.3.2 Subsurface Sediments--

Twenty-three sediment box or gravity cores of 1-6 ft (0.3-1.8 m) in length were analyzed from Hylebos, Sitcum, St. Paul, Middle, and City Waterways, and from the Ruston-Pt. Defiance Shoreline. These cores were collected at 18 stations in 13 areas where contaminated surface sediments were found. Additional cores of up to 8 ft (2.4 m) in length were collected using a drilling rig at 17 sites in Blair Waterway as part of a combined effort between the Port of Tacoma and this Commencement Bay Superfund project. Ranges in concentrations (DW) of inorganic chemicals analyzed in composited sediments from different core depths are summarized in Table 3.2. Maximum subsurface and surface sediment concentrations can be used to compare extreme historical and present conditions. A comparison of mean subsurface values with mean surface values from throughout the study area was not made because cores were collected only in areas where substantial contamination by inorganic or organic substances was indicated in surface sediments; surface sediments were collected from multiple sites ranging from low to high contamination.

Maximum subsurface concentrations of most elements were higher by factor of 1.5 to 3 times the maximum surface concentrations reported in Table 3.1. These maximum subsurface and surface sediment concentrations almost always occured in cores from along the Ruston-Pt. Defiance Shoreline. Maximum iron and manganese concentrations in subsurface and surface sediments from this area also fell within this range of differences. These elements are derived from predominantly natural sources that have presumably been reasonably constant over time, although natural variability in accumulations over time and among different sediment types is expected. Therefore, the observed differences may be related to natural variability in sediment deposition, not to a major change in the discharge of metals from pollutant sources. Concentrations of metals (e.g., lead and copper) also did not

TABLE 3.1. CONCENTRATIONS OF U.S. EPA PRIORITY POLLUTANT TRACE METALS AND ADDITIONAL METALS IN SURFACE SEDIMENTS (0-2 cm) FROM COMMENCEMENT BAY AND CARR INLET

	Range (mg/kg dry wt)	Detection Frequency[a]	Location of Maximum
Antimony	U 0.10[b] - 420	142/148	RS-18
Arsenic	2.4 - 12,000	148/148	RS-17
Barium	5.1 - 150	129/129	RS-21
Beryllium	U 0.02 - 0.55	145/148	RS-21
Cadmium	U 0.1 - 180	144/148	RS-18
Chromium	5.4 - 62	148/148	CI-02
Copper	4.9 - 14,000	148/148	RS-21
Iron	6,200 - 120,000	148/148	RS-21
Lead	4.4 - 6,200	148/148	RS-18
Manganese	55 - 750	148/148	RS-18
Mercury	0.01 - 52	147/148	RS-18
Nickel	6.9 - 350	147/147	RS-21
Selenium	U 0.05 - 26	12/148	RS-17
Silver	0.02 - 2.4	138/148	CI-02
Thallium	U 0.10 - 3.2	19/148	RS-18
Zinc	15 - 4,200	148/148	RS-21

[a] Detection frequency includes replicate samples; maximum of 10 percent replication. Original data listed in Appendix IV.

[b] U: Undetected at the detection limit shown.

TABLE 3.2. U.S. EPA PRIORITY POLLUTANT TRACE METALS AND ADDITIONAL METALS IN SUBSURFACE SEDIMENTS FROM COMMENCEMENT BAY

	Range (mg/kg dry wt)	Detection Frequency[a]	Location of Maximum
Antimony	U 0.1[b] - 200	93/130	RS-61-H3
Arsenic	1.4 - 30,000	130/130	RS-62-H1
Barium[c]	9.2 - 460	129/130	RS-61-H3
Beryllium	U 0.05 - 1.0	114/130	RS-61-H1
Cadmium	U 0.10 - 280	81/130	RS-61-H1
Chromium	8.9 - 130	130/130	RS-61-H1
Copper	10 - 36,000	130/130	RS-61-H1
Iron	8,700 - 190,000	130/130	RS-61-H1
Lead	U 2.0 - 10,000	125/130	RS-61-H1
Manganese	63.0 - 1,900	130/130	RS-61-H1
Mercury	U 0.04 - 21	98/129	RS-62-H2
Nickel	0.36 - 930	130/130	RS-61-H1
Selenium	U 0.05 - 26	8/130	RS-62-H2
Silver[c]	U 0.05 - 18	77/130	RS-60-H1
Thallium	U 0.1 - 2.0	6/130	RS-61-H1
Zinc[c]	18 - 13,000	130/130	RS-61-H5

[a] Detection frequency includes replicate samples; maximum of 10 percent replication. Original sample data listed in Appendix IV.

[b] U: Undetected at the detection limit shown.

[c] Ratios of maximum observed subsurface to surface concentrations were greater than three for only the following metals: barium (ratio 3.1); silver (ratio 7.5); zinc (ratio 3.1).

vary substantially with depth in cores from Wheeler-Osgood Waterway, the middle of the main channel of City Waterway, and St. Paul Waterway.

All metal concentrations (DW) in the bottom interval analyzed from cores drilled in Blair Waterway were comparable to Puget Sound reference conditions (see Section 3.1.3.3). Similarly low metal concentrations were found in the bottom interval of box or gravity cores from four stations in Hylebos Waterway (cores HY-60, HY-60A, HY-61, and HY-62; Figure 2.3). Concentrations of metals at the bottom of four cores were within a factor of two of Puget Sound reference conditions (HY-63A, CI-60, CI-62, and SP-60). Concentrations of at least one metal in the bottom of 11 other cores were greater than two times maximum Puget Sound reference conditions (cores CI-61, CI-63, HY-60B, HY-63, HY-63B, HY-63C, MD-60, RS-60, RS-61, RS-62, and SI-60).

3.1.3.3 Sediment Metals of Concern--

The range of trace metal concentrations in sediments from Puget Sound reference areas are summarized in Table 3.3. It is assumed that the range of reference concentrations provides a reasonable measure of the possible variability in concentrations in relatively uncontaminated sediments. Eight metals are of concern because their concentrations (DW) in Commencement Bay surface sediments exceeded the range of concentrations for Puget Sound reference areas. These metals of concern are listed in Table 3.4. Areas containing the most contaminated sediments are also summarized in the table. Distributions of these elements within Commencement Bay study areas and their relative importance in problem areas are discussed in Section 6.

Concentrations of beryllium, chromium, and silver in Commencement Bay surface sediments were within the ranges observed in Puget Sound reference areas. Thus, there is no evidence that surface subtidal sediments in Commencement Bay are contaminated by these three elements above reference conditions and they have not been defined as metals of concern. Silver was found to be elevated above reference conditions in at least one interval of cores from Stations CI-60, CI-61, HY-60B, RS-60, RS-62, and SI-60. Therefore, sediments contaminated with silver may be exposed during dredging operations in these areas. Beryllium and chromium concentrations did not exceed the range of Puget Sound reference conditions in any subsurface sample.

Except for stations directly off ASARCO plant outfalls on the Ruston-Pt. Defiance Shoreline, surface and subsurface sediments in Commencement Bay do not appear to be contaminated by selenium or thallium at levels that exceed Puget Sound reference conditions. Given this distribution, selenium and thallium are not classified as chemicals of general concern. High concentrations of barium were found in sediments from a few stations along the Ruston-Pt. Defiance Shoreline, at levels ranging from 10 to 22 times reference conditions. Barium concentrations in the remaining Commencement Bay study areas ranged from 2 to 8 times reference values (available only from Carr Inlet). Optimal procedures for the efficient digestion of barium salts were not available. Hence, the concentrations reported may underestimate the total in both Commencement Bay and Carr Inlet sediments. However, there are no known major sources of barium in the region and barium is not defined as a contaminant of general concern.

TABLE 3.3. SUMMARY OF METAL CONCENTRATIONS IN SEDIMENTS FROM PUGET SOUND REFERENCE AREAS

	Range (mg/kg dry wt)	Mean (mg/kg dry wt)	Detection Frequency	Reference Sites[a]
Antimony	U 0.1[b] - 1.7	0.32[c] - 0.38[d]	12/32	1,2,3,4,7,8,9
Arsenic	1.9 - 17	7.2	34/34	1,2,3,4,7,8,9
Beryllium	0.07 - 5.5	2.3	26/26	1,2,3,4,5,9
Barium	5.6 - 7.8	6.9	4/4	1
Cadmium	0.1 - 1.9	0.67	24/24	1,2,3,4,6,9
Chromium	9.6 - 130	54	38/38	1-9
Copper	5 - 74	32	28/28	1,2,3,4,5,6,9
Lead	U 0.1 - 24	9.8[c] - 9.8[d]	21/28	1,2,3,4,5,6,9
Mercury	0.01 - 0.28	0.08	38/38	1-9
Nickel	4 - 47	28	26/26	1,2,3,4,5,9
Selenium	U 0.1 - 1.0	0.36[c] - 0.62[d]	16/24	1,2,3,4,6,9
Silver	0.02 - 3.3	1.2	26/26	1,2,3,4,5,9
Thallium	U 0.1 - 0.2	0.05[c] - 0.12[d]	8/22	1,2,3,4,9
Zinc	15 - 100	62	26/26	1,2,3,4,5,9

[a] Reference sites:

1. Carr Inlet	4. Case Inlet	7. Nisqually Delta
2. Samish Bay	5. Port Madison	8. Hood Canal
3. Dabob Bay	6. Port Susan	9. Sequim Bay

[b] U: Undetected at the method detection limit shown.

[c] Mean calculated using 0.00 for undetected values.

[d] Mean calculated using the reported detection limit for undetected values.

References:

(Site 1)	This report; Crecelius et al. (1975).
(Site 2)	Battelle (1985).
(Site 3)	Battelle (1985).
(Site 4)	Crecelius et al. (1975); Malins et al. (1980).
(Site 5)	Malins et al. (1980).
(Site 6)	Malins et al. (1981).
(Site 7)	Crecelius et al. (1975).
(Site 8)	Crecelius et al. (1975).
(Site 9)	Battelle (1985).

TABLE 3.4. COMPARISON OF THE RANGE IN ELEVATIONS ABOVE REFERENCE (EAR) FOR INORGANIC CONTAMINANTS OF CONCERN IN SURFACE SEDIMENTS (0-2 cm) FROM COMMENCEMENT BAY

	Elevation Above Reference[a]			Areas Where Sediments Exceeded 10x Threshold[c]
	Range	Median	Threshold[b]	
Antimony	0.5 - 2,300	6.0	9.3	RS,HY
Arsenic	1.6 - 3,600	7.3	5.0	RS,HY
Cadmium	0.1 - 190	2.4	2.0	RS
Copper	1.7 - 2,200	13	12	RS
Lead	0.9 - 680	7.3	2.6	RS,CI,MD,SI
Mercury	0.9 - 1,200	5.0	6.5	RS,HY,MD
Nickel	0.4 - 20	0.9	2.7	none RS
Zinc	1.1 - 220	5.0	5.3	RS

[a] Dry-weight concentration in Commencement Bay sediments divided by the average concentration measured in six Carr Inlet reference sediments.

[b] The threshold EAR is defined as the ratio of the maximum reference sediment concentration in Puget Sound divided by the average for six Carr Inlet reference sediments. Above the threshold EAR, the dry-weight concentration of a Commencement Bay sediment contaminant would exceed the maximum concentration (or detection limit) reported for any Puget Sound reference site listed in Table 3.3.

[c] The contaminant EAR in sediments from at least one station in each area listed exceeded the threshold level indicated by an order of magnitude. Sediments in underlined areas had the highest observed values. "None" indicates that no sediment analyzed from Commencement Bay study areas exceeded the threshold by an order of magnitude. The area with the highest value is still listed.

3.1.4 Sediment Organic Compounds

3.1.4.1 Surface Sediments--

Ranges in concentrations (DW) for the 133 U.S. EPA organic priority pollutant and additional hazardous substance list compounds analyzed in Commencement Bay and Carr Inlet surface subtidal sediments are summarized in Table 3.5. These results include data for the 1984 Blair Waterway Dredging Survey in which similar analytical methods were used. Ranges in concentrations for an additional 14 tentatively identified compounds specifically searched for in GC/MS analyses of surface sediments are presented in Table 3.6. Most of these latter compounds were not analyzed for in the Blair Waterway Dredging Survey. Organic compounds in tables used in this report are grouped with other chemically related compounds and, except for pesticides, are listed in order of increased structural complexity within each group. Structures and molecular weights of all compounds discussed are shown in Appendix I.

The most frequently detected organic compounds in sediment samples were aromatic hydrocarbons containing one to six rings. The distributions of these and other compounds that were frequently detected or were detected at high concentrations at a few sites are summarized in Section 3.1.5.3.

Fifty-three compounds were undetected in all surface sediments at the detection limits summarized in Table 3.5. Special analyses were conducted for 2,3,7,8-tetrachlorodibenzo-p-dioxin in 32 sediment samples. Dioxin was undetected at a detection limit of <0.3 ug/kg DW in all cases. Additional undetected substances include most of the organonitrogen compounds (bases), pesticides, and volatile compounds. Volatile compounds were analyzed for at only 20 stations, however. Compounds that were only detected a few times at low concentrations (i.e., <10 ug/kg DW) include several substituted phenols and halogenated ethers. It cannot be determined if these 53 compounds contribute to observed sediment toxicity or biological effects if they are present at concentrations below the low part per billion detection limits attained. Within the scope of the Superfund investigation, these compounds do not appear to be of major concern for Commencement Bay.

Pesticides were analyzed by GC/MS in all sediment samples except those analyzed in the Blair Waterway Dredging Survey, which were analyzed by electron capture gas chromatography (EC/GC). The GC/MS technique is less sensitive than pesticide analysis by EC/GC, but provides positive confirmation of compound identifications. Interfering substances can result in false identifications using EC/GC. By using GC/MS, less sensitive pesticide detection limits were attained than in most historical analyses for Commencement Bay, all conducted using EC/GC. However, there were no confirmations of the high historical concentrations in intertidal and subtidal sediments summarized by Johnson et al. (1983) (i.e., on the order of hundreds of ug/kg DW for pesticides such as aldrin, lindane, or DDT). The only pesticide detected and confirmed by GC/MS identification was DDT at Station CI-01 (50 ug/kg DW). It appears that the previous EC/GC reports of substantial pesticide contamination in some study areas are incorrect, or at least no longer apply to current sediment conditions. Recent pesticide analyses using EC/GC reported for the 1984 Blair Waterway Dredging Survey are included

TABLE 3.5. CONCENTRATIONS OF U.S. EPA ORGANIC PRIORITY POLLUTANTS AND ADDITIONAL HAZARDOUS SUBSTANCE LIST (HSL) COMPOUNDS IN SURFACE SEDIMENTS (0-2 cm) FROM COMMENCEMENT BAY AND CARR INLET

	Phenols (acids; 4)	Range (ug/kg dry wt)	Detection Frequency[a]	Location of Maximum
65[b]	phenol	U 1.0[c]- 2,100	134/158	HY-16
HSL	2-methylphenol	U 0.6 - 100	72/143	SP-13
HSL	4-methylphenol	U 1.0 - 96,000	114/143	SP-14
34	2,4-dimethylphenol	U 0.5 - 210	36/158	RS-16
	Substituted Phenols (acids; 10)			
24	2-chlorophenol	0.1 - U 25	8/158	d
31	2,4-dichlorophenol	0.1 - U 50	12/158	d
22	4-chloro-3-methylphenol	0.1 - U 50	3/158	d
21	2,4,6-trichlorophenol	0.2 - 160	12/158	HY-31
HSL	[e]2,4,5-trichlorophenol	U 10 - 150	2/126	MD-11
64	pentachlorophenol	0.1 - 860	45/158	BL-30
57	2-nitrophenol	0.1 - U 50	10/158	d
59	2,4-dinitrophenol	U 0.5 - U 190	0/32	undetected
60	4,6-dinitro-o-cresol	U 0.5 - U 500	0/158	undetected
58	4-nitrophenol	U 0.5 - U 1,900	3/158	B11
	Low Molecular Weight Aromatic Hydrocarbons (neutrals; 7)			
55	naphthalene	U 0.5 - 5,500	153/158	CI-12
HSL	2-methylnaphthalene	1.0 U - 1,200	146/156	RS-18 & CI-02
77	acenaphthylene	U 0.5 - 650	149/158	CI-21
1	acenaphthene	U 0.5 - 2,500	147/158	RS-18
80	fluorene	0.5 - 3,100	151/157	RS-18
81	phenanthrene	2 - 11,000	157/157	RS-18
78	anthracene	U 0.5 - 1,600	155/157	CI-21
	High Molecular Weight Aromatic Hydrocarbons (neutrals; 10)			
39	fluoranthene	11 - 8,100	158/158	RS-18
84	pyrene	11 - 5,800	158/158	HY-19
72	benzo(a)anthracene	4 - 3,500	155/156	HY-19
76	chrysene	U 5 - 6,100	155/156	HY-16
74	benzo(b)fluoranthene	Combined with benzo(k)fluoranthene		
75	benzo(k)fluoranthene	U 5 - 8,800	135/136	HY-16
73	benzo(a)pyrene	3 - 6,100	154/156	HY-22
83	indeno(1,2,3-c,d)pyrene	U 0.5 - 2,700	148/157	HY-22
82	dibenzo(a,h)anthracene	0.4 - 1,500	137/157	HY-22
79	benzo(g,h,i)perylene	U 0.5 - 1,900	147/157	HY-16

TABLE 3.5. (Continued)

Chlorinated Aromatic Hydrocarbons (neutrals; 6)				
26	1,3-dichlorobenzene	U 0.5 - 210	57/158	BL-19 HY-31
27	1,4-dichlorobenzene	U 0.5 - 290	104/158	CI-11
25	1,2-dichlorobenzene	0.1 - 350	47/158	CI-16
8	1,2,4-trichlorobenzene	U 0.5 - 260	25/158	HY-46 & HY-22
20	2-chloronaphthalene	U 0.5 - U 25	0/158	**undetected**
9	hexachlorobenzene (HCB)	0.2 - 730	34/158	HY-22
Chlorinated Aliphatic Hydrocarbons (neutrals; 3 plus CBD isomers)				
12	[e]hexachloroethane	U 0.5 - 2,800	4/158	HY-22
xx	trichlorobutadiene isomers	U 0.5 - 43,000	54/145	HY-46
xx	tetrachlorobutadiene isomers	U 10 - 18,000	84/145	HY-46
xx	pentachlorobutadiene isomers	U 10 - 3,600	46/145	HY-46
52	hexachlorobutadiene	U 0.5 - 940	33/158	HY-46
53	[e]hexachlorocyclopentadiene	U 0.5	0/18	**undetected**
Halogenated Ethers (neutrals; 5)				
18	bis(2-chloroethyl) ether	0.2 - U 50	4/158	**d**
42	bis(2-chloroisopropyl) ether	U 0.5 - U 400	1/158	**d**
43	bis(2-chloroethoxy)methane	U 0.5 - 91	1/140	B-14
40	4-chlorophenyl phenyl ether	U 0.5 - U 25	0/158	**undetected**
41	4-bromophenyl phenyl ether	U 0.5 - U 25	0/158	**undetected**
Phthalates (neutrals; 6)				
71	dimethyl phthalate	B 0.5[c] - 1,100	78/157	HY-21
70	diethyl phthalate	B 0.5 - 120	37/157	HY-48
68	di-n-butyl phthalate	B 0.5 - 9,800	94/157	CB-11
67	butyl benzyl phthalate	U 0.5 - 890	51/150	HY-35
66	bis(2-ethylhexyl)phthalate	B 0.5 -G 8,000	61/157	CI-02
69	di-n-octyl phthalate	U 0.5 - 420	33/155	B-09
Miscellaneous oxygenated compounds (neutrals; 5)				
54	isophorone	U 0.5 - U 130	13/157	**d**
HSL	benzyl alcohol	U 10 - 500	87/126	HY-21
HSL	benzoic acid	U 1.0 - 8,000	63/143	BL-16
129	2,3,7,8-tetrachlorodibenzo-p-dioxin	U 0.3 - U 0.2	0/32	**undetected**
HSL	dibenzofuran	U 1.0 - 2,000	131/143	RS-18

TABLE 3.5. (Continued)

Organonitrogen Compounds (bases; 13)				
HSL	aniline	U 1.0 - 1,400	3/143	CI-11
56	nitrobenzene	U 0.5 - U 25	2/157	d
63	n-nitroso-di-n-propylamine	U 0.5 - U 50	2/151	d
HSL	4-chloroaniline	U 50 - U 250	0/126	undetected
HSL	2-nitroaniline	U 50 - U 250	0/126	undetected
HSL	3-nitroaniline	U 50 - U 250	0/126	undetected
HSL	4-nitroaniline	U 50 - U 250	0/126	undetected
36	[e]2,6-dinitrotoluene	U 0.5 - U 50	8/157	d
35	2,4-dinitrotoluene	U 0.5 - 28	3/157	CI-01
62	n-nitrosodiphenylamine	0.2 - 610	31/157	RS-18
37	[e]1,2-diphenylhydrazine	U 0.5 - 1,200	4/158	BL-12
5	benzidine (4,4'-diaminobiphenyl)	U 0.5	0/13	undetected
28	3,3'-dichlorobenzidine	U 0.5 - U 500	0/139	undetected
Pesticides (neutrals; 18)				
93	p,p'-DDE	U 0.01- U 50	5/157	d
94	p,p'-DDD	U 0.03- U 50	4/158	d
92	[e]p,p'-DDT	U 0.01- U 50	11/158	d
89	aldrin	U 0.01- U 50	1/158	d
90	dieldrin	U 0.01- U 50	0/158	undetected
91	chlordane	U 10 - U 50	0/158	undetected
95	alpha-endosulfan	U 0.02- U 50	0/157	undetected
96	beta-endosulfan	U 0.03- U 50	0/157	undetected
97	endosulfan sulfate	U 0.03- U 50	0/157	undetected
98	endrin	U 0.03- U 50	0/158	undetected
99	endrin aldehyde	U 0.02- U 50	0/157	undetected
100	heptachlor	U 0.02- U 50	1/158	d
101	heptachlor epoxide	U 0.02- U 50	0/158	undetected
102	alpha-HCH	U 0.01- U 50	0/158	undetected
103	beta-HCH	U 0.03- U 50	0/158	undetected
104	delta-HCH	U 0.02- U 50	0/158	undetected
105	gamma-HCH (lindane)	U 0.01- U 50	0/158	undetected
113	toxaphene	U 10 - U 22	0/32	undetected
PCBs (neutrals; used as total PCBs only)				
xx	Total PCBs (primarily 1254/1260)	4 - 2,000	113/144	HY-22

TABLE 3.5. (Continued)

Volatile Halogenated Alkanes (neutrals; 17)				
	dichlorodifluoromethane (removed)	U 10	0/21	undetected
45	chloromethane	U 10	0/21	undetected
46	bromomethane	U 5 - U 10	0/36	undetected
16	chloroethane	U 5 - U 10	0/36	undetected
44	methylene chloride (dichloromethane)			not reported
	fluorotrichloromethane (removed)	U 10	0/21	undetected
13	1,1'-dichloroethane	U 5 - U 10	0/36	undetected
23	[e]chloroform	U 1.0 - U 10	3/36	d
10	1,2-dichloroethane	U 5 - U 10	0/36	undetected
11	1,1,1-trichloroethane	U 5 - U 10	0/36	undetected
6	carbon tetrachloride	U 5 - U 10	0/36	undetected
48	bromodichloromethane	U 5 - U 10	0/36	undetected
32	1,2-dichloropropane	U 5 - U 10	0/36	undetected
51	chlorodibromomethane	U 5 - U 10	0/36	undetected
14	1,1,2-trichloroethane	U 5 - 38	2/36	B-11
47	bromoform	U 5 - U 10	0/36	undetected
15	1,1,2,2-tetrachloroethane	U 5 - U 10	0/36	undetected
Volatile Halogenated Alkenes (neutrals; 6)				
88	vinyl chloride	U 5 - U 10	0/36	undetected
29	1,1'-dichloroethene	U 5 - U 10	1/36	d
30	trans-1,2-dichloroethene	U 1.1 - U 10	1/36	d
33	cis and trans-1,3-dichloropropene	U 5 - U 10	0/36	undetected
87	trichloroethene	U 5 - U 10	0/36	undetected
85	tetrachloroethene	U 5 - 210	11/36	HY-17
Volatile Aromatic Hydrocarbons (neutrals; 5)				
4	benzene	U 0.15- U 10	4/36	d
86	toluene	U 0.19- U 10	3/36	d
38	ethylbenzene	U 0.08- 50	11/36	HY-17
HSL	styrene (ethenylbenzene)	U 20		undetected
HSL	total xylenes	U 20 - 160	10/21	HY-17
Volatile Chlorinated Aromatic Hydrocarbons (neutrals; 1)				
7	chlorobenzene	U 5 - U 10	0/36	undetected
Volatile Unsaturated Carbonyl Compounds (base/neutrals; 2)				
2	acrolein (an unsaturated aldehyde)	U 100	0/21	undetected
3	acrylonitrile (an unsaturated nitrile)	U 100	0/21	undetected
Volatile Ethers (neutrals; 2)				
	bis(chloromethyl)ether			not analyzed
19	2-chloroethylvinyl ether	U 5 - U 100		undetected

TABLE 3.5. (Continued)

Volatile Ketones (neutrals; 4)					
HSL	acetone	U 20		0/20	**undetected**
HSL	2-butanone	U 20		0/20	**undetected**
HSL	2-hexanone	U 20		0/20	**undetected**
HSL	4-methyl-2-pentanone	U 20		0/20	**undetected**
Miscellaneous Volatile Compounds (neutrals; 2)					
HSL	carbon disulfide	5	- U 10	9/20	**d**
HSL	vinyl acetate	U 20		0/20	**undetected**

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[a] Detection frequency includes replicate samples; maximum of 10 percent replication. Original sample data listed in Appendix V.

[b] Indicates U.S. EPA priority pollutant number.

[c] Qualifiers -

B: Value corrected for blank contributions down to the detection limit shown.

E: Estimated value.

G: Estimated value is greater than the minimum shown.

N/R: Not reported.

U: Undetected at the detection limit stated (ug/kg or ppb dry weight sediment).

Z: Value corrected for blank contributions; resulting value still exceeds the detection limit.

[d] Compound detected at concentration between the minimum and maximum detection limits shown at a few stations only.

[e] Compounds detected only under special circumstances and were not included in routine statistical analyses of surface sediments.

TABLE 3.6. CONCENTRATIONS OF TENTATIVELY IDENTIFIED COMPOUNDS IN SURFACE SEDIMENTS (0-2 cm) FROM COMMENCEMENT BAY AND CARR INLET

	Range (ug/kg dry wt)	Detection Frequency	Location of Maximum
Alkylated aromatic hydrocarbons			
1-methyl-2-(1-methylethyl)benzene	U[a] - 6600	104/123	SP-14
1,1'-biphenyl	U - 1100	102/123	RS-18
2-methyl phenanthrene	U - 2400	102/122	RS-18
1-methyl phenanthrene	U - 1300	85/122	RS-18
1-methylpyrene	U - 1500	86/123	HY-17
retene	U - 2000	113/123	SI-15
2-methylpyrene	U - 3400	93/123	HY-16
Diterpenoid hydrocarbons			
isopimaradiene	U - 5900	104/123	SP-14
unidentified diterpene (possibly kaur-16-ene)	U - 5200	97/123	SP-14
Substituted hydrocarbons			
dibenzothiophene	U - 1100	81/123	RS-18
pentachlorocyclopentane (isomer)	U - 270	37/123	HY-46
Miscellaneous oxygenated compounds			
2-methoxyphenol	U - 3900	60/119	SP-14
9-hexadecenoic acid methyl ester	U - 7300	99/123	HY-36
coprostanol (a fecal sterol indicator)	U - 2800	62/123	SP-11

[a] U: not found during a mass spectral search of a sample extract. Actual detection limits for tentatively identified compounds were not assigned in these cases.

in the Table 3.2 summary. High pesticide concentrations were not found, although DDTs were detected at <1-14 ug/kg DW in a few samples, aldrin was reported at <1 ug/kg DW in three samples, and heptachlor was reported in one sample at 0.8 ug/kg DW and in another at 1.5 ug/kg DW. Neither GC/MS analysis nor a confirming EC/GC analysis using a column of differing polarity were conducted on these samples, as required for verification of these GC/EC results.

3.1.4.2 Subsurface Sediments--

Subsurface sediments were collected from 13 areas with contaminated surface sediments, in addition to the more detailed sampling conducted as part of the Blair Waterway Dredging Study (see discussion in Section 3.1.3.2). Ranges in concentrations (DW) of organic compounds analyzed in composited sediments from different core depths are summarized in Table 3.7. Original data for individual samples are reported in Appendix V. Data for half of the 134 samples were derived from the 1984 Blair Waterway Dredging Survey, although not all organic compounds listed in Table 3.7 were analyzed for in the dredging survey.

Aromatic hydrocarbons were the most frequently detected compounds in subsurface sediments, as they were in surface sediments. Organic compounds with at least a fivefold difference between the maximum concentrations in subsurface and surface sediments are indicated in Table 3.8. Ratios of subsurface to surface concentrations (DW) are also shown. As discussed for metals (Section 3.1.3.2), this presentation of the data is useful for comparing maximum historical conditions with maximum current day conditions.

Compounds typically undetected or reported only occasionally at low part per billion concentrations in surface and subsurface sediments include nitrophenols, 2-chloronaphthalene, halogenated ethers, most organonitrogen compounds, and pesticides. Volatile compound analyses were conducted on only one subsurface sediment sample collected at a Hylebos Waterway site heavily contaminated with chlorinated ethenes.

Organic compound concentrations in the bottom interval of most of the Blair Waterway Dredging Survey drilling cores did not exceed the range observed for Puget Sound reference sediments. Exceptions included a slight elevation of PCB 1248 (35 ppb) at Station B-04 and occasional elevations of individual hydrocarbons, primarily naphthalene. Hydrocarbon concentrations in the bottom interval of all sediment box and gravity cores from other Commencement Bay areas exceeded Puget Sound reference conditions typically by a factor of 2-10 (in some cases, by a factor of >10). This was true even in the bottom interval of the eight cores that had no evidence of metals contamination.

Other organic compounds found at greater than reference levels in the bottom interval of cores with no evidence of metals contamination included phenol and methylated phenols, di-n-butyl, di-n-octyl and dimethyl phthalate esters, benzyl alcohol, dibenzofuran, 1,3- and 1,4-dichlorobenzene, chlorinated butadienes, and hexachlorocyclopentadiene. Total PCB contamination exceeding Puget Sound reference conditions was detected in the bottom interval of cores at three stations (CI-62, RS-62, and SP-60 at 310, 340, and 210 ug/kg DW, respectively).

TABLE 3.7. U.S. EPA ORGANIC PRIORITY POLLUTANTS AND ADDITIONAL HAZARDOUS SUBSTANCE LIST (HSL) COMPOUNDS IN SUBSURFACE SEDIMENTS FROM COMMENCEMENT BAY

		Range (ug/kg dry wt)	Detection Frequency[a]	Location of Maximum[b]
Phenols				
65[c]	phenol	U 1.0[d]- Z 6,100[d]	84/116	CI-62-H2
HSL	2-methylphenol	U 10 - 1,900	32/ 65	HY-63A-H3
HSL	4-methylphenol	U 10 - 11,000	49/ 65	CI-62-H1
34	2,4-dimethylphenol	U 1.0 - 6,200	28/116	HY-63A-H3
Substituted Phenols				
24	2-chlorophenol	U 1.0 - U 220	4/116	**e**
31	2,4-dichlorophenol	U 1.0 - U 40	3/116	**e**
22	4-chloro-3-methylphenol	U 1.0 - U 20	7/116	**e**
21	2,4,6-trichlorophenol	U 1.0 - U 20	0/116	**undetected**
HSL	2,4,5-trichlorophenol	U 10 - 1,300	1/ 65	HY-63-H1
64	pentachlorophenol	U 1.0 - E14,000[d]	15/116	HY-63-H2
57	2-nitrophenol	U 1.0 - U 80	1/116	**e**
59	2,4-dinitrophenol	U 1.0 - U 550	0/ 51	**undetected**
60	4,6-dinitro-o-cresol	U 1.0 - U 280	1/116	**e**
58	4-nitrophenol	U 2.0 - U 5,000	5/116	**e**
Low Molecular Weight Aromatic Hydrocarbons				
55	naphthalene	U 1.0 - 6,400	124/134	CI-62-H2
	2-methylnapthalene	U 1.0 - 8,100	130/132	CI-62-H2
77	acenaphthylene	U 1.0 - 1,800	108/134	CI-62-H1
1	acenaphthene	U 1.0 - 3,900	110/134	HY-60-H2
80	fluorene	U 1.0 - 5,200	121/134	HY-60-H2
81	phenanthrene	U 1.0 -78,000	132/133	HY-60-H2
78	anthracene	U 1.0 -26,000	129/133	HY-60-H2
High Molecular Weight Aromatic Hydrocarbons				
39	fluoranthene	U 1.0 -130,000	131/134	HY-60-H2
84	pyrene	U 1.0 -130,000	131/134	HY-60-H2
72	benzo(a)anthracene	U 1.0 - 47,000	129/134	HY-60-H2
76	chrysene	U 1.0 - 68,000	130/134	HY-60-H2
74	benzo(b)fluoranthene	Combined with benzo(k)fluoranthene		
75	benzo(k)fluoranthene	2.9 - 66,000	109/109	HY-60A-H2
73	benzo(a)pyrene	U 1.0 - 36,000	128/134	HY-60-H2
83	indeno(1,2,3-c,d)pyrene	U 1.0 - 12,000	120/134	HY-60A-H1

TABLE 3.7. (Continued)

82	dibenzo(a,h)anthracene	U 1.0 - 4,100	111/134	HY-60A-H1
79	benzo(g,h,i)perylene	U 1.0 - 8,600	120/134	HY-60-H2
Chlorinated Aromatic Hydrocarbons				
26	1,3-dichlorobenzene	U 1.0 - 1,400	35/134	CI-62-H1
27	1,4-dichlorobenzene	U 1.0 - 12,000	46/134	CI-60-H2
25	1,2-dichlorobenzene	U 1.0 - 1,900	20/134	CI-62-H1
8	1,2,4-trichlorobenzene	U 1.0 - 490	21/134	HY-63-H3
20	2-chloronaphthalene	U 1.0 - U 50	0/134	**undetected**
9	hexachlorobenzene (HCB)	U 1.0 - 9,500	17/134	HY-63-H2
Chlorinated Aliphatic Hydrocarbons				
12	hexachloroethane	U 1.0 - U 220	1/134	**e**
xx	trichlorobutadiene isomers	U 10 - 92,000	27/ 71	HY-63B-H3
xx	tetrachlorobutadiene isomers	U 10 -500,000	34/ 71	HY-63-H2
xx	pentachlorobutadiene isomers	U 10 -130,000	22/ 71	HY-63-H2
52	hexachlorobutadiene	U 1.0 - 57,000	17/134	HY-63-H2
53	hexachlorocyclopentadiene	N/R[d]- E950	4/ 4	HY-63-H2
Halogenated Ethers (neutrals; 5)				
18	bis(2-chloroethyl) ether	U 1.0 - U 20	0/134	**undetected**
42	bis(2-chloroisopropyl) ether	U 1.0 - U 2,000	1/134	**e**
43	bis(2-chloroethoxy)methane	U 1.0 - U 110	3/134	**e**
40	4-chlorophenyl phenyl ether	U 1.0 - U 10	1/134	**e**
41	4-bromophenyl phenyl ether	U 1.0 - U 10	0/134	**undetected**
Phthalates				
71	dimethyl phthalate	U 1.0 - 13,000	93/134	CI-62-H1
70	diethyl phthalate	U 1.0 - 500	49/134	CI-62-H1
68	di-n-butyl phthalate	U 1.0 - Z 2,200	76/134	CI-62-H1
67	butyl benzyl phthalate	U 1.0 - 460	78/134	CI-60-H1
66	bis(2-ethylhexyl) phthalate	U 1.0 - Z 9,000	88/134	CI-60-H1
69	di-n-octyl phthalate	U 1.0 - 410	55/134	CI-60-H1
Miscellaneous oxygenated compounds				
54	isophorone	U 1.0 - U 50	3/134	**e**
HSL	benzyl alcohol	U 10 - 330	25/ 71	RS-61-H2
HSL	benzoic acid	U 25 - 820	5/ 65	CI-60-H5
129	2,3,7,8-tetrachlorodibenzo-p-dioxin			**not analyzed**
HSL	dibenzofuran	3.9 - 1,700	70/ 71	CI-63-H3
Organonitrogen Compounds				
HSL	aniline	U 20 - U 40	0/ 71	**undetected**
56	nitrobenzene	U 1.0 - U 10	0/134	**undetected**

TABLE 3.7. (Continued)

63	n-nitroso-di-n-propylamine	U 1.0 - 36	11/134	M-02-H1
HSL	4-chloroaniline	U 50 - U 100	0/ 71	**undetected**
HSL	2-nitroaniline	U 50 - U 100	0/ 71	**undetected**
HSL	3-nitroaniline	U 50 - U 100	0/ 71	**undetected**
HSL	4-nitroaniline	U 50 - U 100	0/ 71	**undetected**
36	2,6-dinitrotoluene	U 1.0 - 53	1/134	B-06-H2
35	2,4-dinitrotoluene	U 1.0 - 40	1/134	B-03-H1
62	n-nitrosodiphenylamine	U 1.0 - 230	49/134	CI-61-H1
37	1,2-diphenylhydrazine	U 1.0 - 1,300	4/134	CI-61-H1
5	benzidine (4,4'-diaminobiphenyl)			**not analyzed**
28	3,3'-dichlorobenzidine	U 1.0 - U 200	0/ 78	**undetected**
	n-nitrosodimethylamine			**not analyzed**
Pesticides				
93	p,p'-DDE	U 0.01- U 100	28/134	**e**
94	p,p'-DDD	U 0.03- U 100	22/134	**e**
92	p,p'-DDT	U 0.03- U 100	14/134	**e**
89	aldrin	U 0.01- U 100	2/134	**e**
90	dieldrin	U 0.01- U 100	2/134	**e**
91	chlordane	U 1.1 - U 100	2/134	**e**
95	alpha-endosulfan	U 0.01- U 100	1/134	**e**
96	beta-endosulfan	U 0.03- U 100	1/134	**e**
97	endosulfan sulfate	U 0.02- U 100	3/134	**e**
98	endrin	U 0.03- U 100	0/134	**undetected**
99	endrin aldehyde	U 0.02- U 100	5/134	**e**
100	heptachlor	U 0.01- U 100	1/134	**e**
101	heptachlor epoxide	U 0.01- U 100	1/134	**e**
102	alpha-HCH	U 0.01- U 100	4/134	**e**
103	beta-HCH	U 0.03- U 100	0/134	**undetected**
104	delta-HCH	U 0.02- U 100	1/134	**e**
105	gamma-HCH (lindane)	U 0.01- U 100	0/134	**undetected**
113	toxaphene	U 12 - U 18	2/ 63	**e**
PCBs (used as total PCBs only)				
xx	Total PCBs (primarily 1254/1260)	U 5.0 -17,000	48/133	
Volatile Compounds[f]				
87	trichloroethene	19,000,000	1/ 1	HY-63-H1
85	tetrachloroethene	14,000,000	1/ 1	HY-63-H1

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[a] Detection frequency includes replicate analyses; maximum of 10 percent replication. Original sample data listed in Appendix V.

[b] Locations are listed by area, station number, and horizon (i.e., CI-62-H2 is City Waterway, Station 62, second horizon).

[c] Indicates U.S. EPA priority pollutant number.

TABLE 3.7. (Continued)

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[d] Qualifiers:

B: Value corrected for "blank" contributions down to the detection limit.

E: Estimated value.

N/R: Not reported.

U: Undetected at the detection limit stated (ug/kg or ppb dry weight sediment).

Z: Value corrected for "blank" contributions; resulting value still exceeds the detection limit.

[e] Compound detected at low concentration between minimum and maximum detection limits at a few stations only.

[f] The high concentrations of tri- and tetrachloroethene prevented detection of other volatile compounds at low levels in the single subsurface sample analyzed. Blair Waterway volatiles data for Port of Tacoma Dredging Survey samples are not reported, but volatiles were typically undetected at 5 ug/kg in these samples.

TABLE 3.8. ORGANIC COMPOUNDS WITH AT LEAST A FIVEFOLD DIFFERENCE BETWEEN MAXIMUM SUBSURFACE AND SURFACE SEDIMENT CONCENTRATIONS

	Ratio of Maximum Observed Concentrations[a] (Subsurface Concentration Exceeds Surface Concentration)
2-methylphenol	19
2,4-dimethylphenol	30
2,4,5-trichlorophenol	8.1
pentachlorophenol	16
2-methylnaphthalene	6.8
phenanthrene	7.1
anthracene	16
fluoranthene	16
pyrene	22
benzo(a)anthracene	13
chrysene	11
total benzofluoranthenes	7.5
benzo(a)pyrene	5.9
1,3-dichlorobenzene	6.7
1,4-dichlorobenzene	41
1,2-dichlorobenzene	5.4
hexachlorobenzene (HCB)	13
trichlorobutadiene isomers	2.1[b]
tetrachlorobutadiene isomers	28
pentachlorobutadiene isomers	36
hexachlorobutadiene	61
dimethyl phthalate	12
	(Surface Concentrations Exceeds Subsurface Concentration)
4-methylphenol	0.11
2,4,6-trichlorophenol	0.13[c]
di-n-butylphthalate	0.2
benzoic acid	0.1
aniline	0.03[c]

[a] Maximum subsurface concentration divided by the maximum surface concentration.

[b] Included for comparison with other butadiene isomers.

[c] Undetected in subsurface sediment; detection limit used for calculation.

3.1.4.3 Sediment Organic Compounds of Concern--

The range of organic compound concentrations in sediments from Puget Sound reference areas is summarized in Table 3.9. These data are compiled from this study (Carr Inlet) as well as from previous investigations funded by various agencies throughout Puget Sound. Data for several compounds were available only for the current study of Carr Inlet because full-scan analyses were not always conducted in other areas. Detection limits in some reference areas exceeded 50 ug/kg DW for several compounds. Detection limits for recent Carr Inlet samples ranged from 0.5 to 50 ug/kg DW for almost all compounds. To provide a comparable data set, a maximum detection limit of 50 ug/kg DW was set for the acceptance of data from other reference sites included in the ranges reported in Table 3.9.

Eighteen organic compounds and compound groups are of concern because their concentrations (DW) in Commencement Bay surface sediments exceed the concentration ranges for Puget Sound reference sediments. These organic chemicals of concern are listed in Table 3.10. Compounds listed in Table 3.10 were detected at elevated levels at several stations within an area, and often in several areas. Chemicals with similar distributional patterns throughout Commencement Bay sediments, as demonstrated by statistical correlations, and/or with closely related chemical behavior (e.g., chlorinated benzenes) have been combined into contaminant groups for ease of analysis. Results of statistical correlation analyses for inorganic and organic contaminants over the entire study area and within large areas (i.e., Hylebos, Blair, and City Waterways) are presented Section 3.1.5.

Of the six groups listed in Table 3.10, only the phthalates do not always show a spatial correlation among individual phthalates within the group. The chlorinated benzenes showed good correlation among individual compounds (i.e., r=0.7 to r=0.98) with the exception of 1,3-dichlorobenzene which was moderatley correlated (i.e., r=0.55 to r=0.63). This lack of spatial correlation is most likely the result of different sources for the chemicals rather than analytical variability. Individual components of these groups will be discussed as appropriate w hen specific contaminated areas are reviewed.

Organic compounds listed in Table 3.5 as undetected in all Commencement Bay and Carr Inlet sediments are not considered to be of concern. Substances found at only a few stations at low parts per billion levels (and often below the detection limits of most other stations) are also not of general concern. Six compounds not included in Table 3.10 were detected at levels greater than the maximum observed in Puget Sound reference areas, but only in one or two samples. These compounds include 2,4,6-trichlorophenol, 2,4,5-trichlorophenol, bis-2-chloroethoxymethane, 2,4-dinitrotoluene, aniline, and 1,1,2-trichloroethane. While these compounds were not detected at a sufficient number of sites to warrant statistical analysis of their spatial distributions and potential relationships to sediment toxicity or biological effects, sites contaminated with these compounds will be discussed. The possible contribution of these compounds to observed toxicity or biological effects at these selected sites will also be considered.

TABLE 3.9. SUMMARY OF ORGANIC COMPOUND CONCENTRATIONS IN SEDIMENTS FROM PUGET SOUND REFERENCE AREAS

Substance[a]		Range (ug/kg dry wt)	Mean (ug/kg dry wt)	Detection Frequency	Reference Sites[b]
Phenols					
65	phenol	U 10 - 62[c]	11[d] - 37[e]	3/13	1,2,3
HSL	2-methylphenol	U 10	---	0/4	---
HSL	4-methylphenol	U 10 - 32	14 - 20	2/4	1
34	2,4-dimethylphenol	U 1 - U 10	---	0/6	1
Substituted Phenols					
24	2-chlorophenol	U 0.5 - U 5	---	0/6	1
31	2,4-dichlorophenol	U 0.5 - U 10	---	0/6	1
22	4-chloro-3-methylphenol	U 0.5 - U 10	---	0/6	1
21	2,4,6-trichlorophenol	U 0.5 - U 10	---	0/6	1
HSL	2,4,5-trichlorophenol	U 10	---	0/4	1
64	pentachlorophenol	0.1 - U 50	0.02 - 33	1/6	1
57	2-nitrophenol	0.1 - U 10	---	1/6	1
59	2,4-dinitrophenol	U 0.5	---	0/6	1
60	4,6-dinitro-o-cresol	U 0.5 - U 100	---	0/6	1
58	4-nitrophenol	U 0.5 - U 100	---	0/6	1
Low Molecular Weight Aromatic Hydrocarbons					
55	naphthalene	U 0.5 - U 40	5.6 - 22	10/20	1,2,3,4,5,6
77	acenaphthylene	U 0.1 - U 40	0.08 - 17	1/20	1,2,3,4,5,6
1	acenaphthene	U 0.1 - U 40	0.48 - 17	4/20	1,2,3,4,5,6
80	fluorene	U 0.1 - 40	3.0 - 19	7/21	All
81	phenanthrene	5 - 170	19 - 35	11/17	1,2,3,6,7
78	anthracene	U 0.5 - U 40	2.7 - 22	7/17	1,2,3,6,7
HSL	2-methylnaphthalene	1 - 20	7.5 - 9.5	6/10	1,4,5,6
High Molecular Weight Aromatic Hydrocarbons					
39	fluoranthene	7 - 100	32 - 41	17/22	All
84	pyrene	8 - 120	30 - 41	16/22	All
72	benzo(a)anthracene	4 - U 40	3.7 - 23	8/17	1,2,3,6,7
76	chrysene	U 5 - U 40	6.4 - 26	8/17	1,2,3,6,7
74	benzo(b)fluoranthene	U 5 - 94	17 - 33	12/21	All
75	benzo(k)fluoranthene	U 5 - 94	17 - 33	12/21	All
73	benzo(a)pyrene	U 0.37- 40	9.3 - 10	10/14	1,3,4,5,6,7
83	indeno(1,2,3-c,d)pyrene	U 0.37- 30	7.4 - 9.2	6/12	1,4,5,6,7
82	dibenzo(a,h)anthracene	0.4 - U 5	0.08 - 4.1	1/5	1
79	benzo(g,h,i)perylene	3 - 20	3.8 - 7.2	2/6	1,7

TABLE 3.9. (Continued)

Chlorinated Aromatic Hydrocarbons					
26	1,3-dichlorobenzene	U 0.06- U 40	0.004 - 19	1/18	1,2,3,4,5
27	1,4-dichlorobenzene	U 0.06- U 40	0.004 - 19	1/18	1,2,3,4,5
25	1,2-dichlorobenzene	U 0.06- U 40	0.004 - 19	1/18	1,2,3,4,5
8	1,2,4-trichlorobenzene	U 0.5- U 5	---	0/6	1
20	2-chloronaphthalene	U 0.5- U 50	---	0/6	1
9	hexachlorobenzene (HCB)	0.01- U 10	0.07 - 3.5	6/12	1,4,5,6
Chlorinated Aliphatic Hydrocarbons					
12	hexachloroethane	U 0.5- U 50	---	0/6	1
xx	trichlorobutadiene	U 0.03- U 25	0.27 - 7.9	5/12	1,4,5,6
xx	tetrachlorobutadiene isomers	U 0.04- U 25	1.6 - 9.2	5/12	1,4,5,6
xx	pentachlorobutadiene isomers	0.03- U 25	0.15 - 7.7	5/12	1,4,5,6
52	hexachlorobutadiene	U 0.03- U 25	0.07 - 8.5	5/12	1,4,5,6
53	hexachlorocyclopentadiene	**not analyzed**			
Halogenated Ethers					
18	bis(2-chloroethyl) ether	0.3 - U 10	---	1/6	1
42	bis(2-chloroisopropyl) ether	U 0.5 - U 10	---	0/6	1
43	bis(2-chloroethoxy)methane	U 10	---	0/6	1
40	4-chlorophenyl phenyl ether	U 0.5 - U 5	---	0/6	1
41	4-bromophenyl phenyl ether	U 0.5 - U 5	---	0/6	1
Phthalate Esters					
71	dimethyl phthalate	U 0.5 - U 50	---	0/5	1
70	diethyl phthalate	9.0 - 11	4 - 18	4/5	1
68	di-n-butyl phthalate	U 20 - 760	160 - 170	3/5	1
67	butyl benzyl phthalate	U 0.5 - U 25	---	0/5	1
66	bis(2-ethylhexyl)phthalate	U 0.5 - U 25	---	0/5	1
69	di-n-octyl phthalate	U 0.5 - U 25	---	0/5	1
Miscellaneous oxygenated compounds					
54	isophorone	U 0.5 - U 130	---	0/5	1
HSL	benzyl alcohol	U 10	---	0/4	1
HSL	benzoic acid	U 25 - 430	210 - 216	3/4	1
129	2,3,7,8-tetrachloro-dibenzo-p-dioxin	**not analyzed**			
HSL	dibenzofuran	U 5	---	0/4	1
Organonitrogen Compounds					
HSL	aniline	U 1.0 - U 20	---	0/6	1
56	nitrobenzene	U 0.5 - U 5	---	0/5	1
63	n-nitroso-di-n-propylamine	U 0.5 - U 10	---	0/5	1
HSL	4-chloroaniline	U 50	---	0/4	1
HSL	2-nitroaniline	U 50	---	0/4	1

TABLE 3.9. (Continued)

HSL	3-nitroaniline	U 50	---	0/4	1
HSL	4-nitroaniline	U 50	---	0/4	1
36	2,6-dinitrotoluene	U 0.5 - U 10	---	0/5	1
35	2,4-dinitrotoluene	U 0.5 - U 5	---	0/5	1
62	n-nitrosodiphenylamine	U 0.5 - U 5	---	0/5	1
37	1,2-diphenylhydrazine	U 0.5 - U 5	---	0/6	1
5	benzidine (4,4'-diamino-biphenyl)	U 0.5	---	0/2	1
28	3,3'-dichlorobenzidine	U 0.5 - U 100	---	0/6	1
Pesticides					
93	p,p'-DDE	U 10 - U 25	---	0/5	1
94	p,p'-DDD	U 10 - U 25	---	0/6	1
92	p,p'-DDT	U 10 - U 25	---	0/5	1
89	aldrin	U 10 - U 25	---	0/6	1
90	dieldrin	U 10 - U 25	---	0/6	1
91	chlordan	U 10 - U 25	---	0/6	1
95	alpha-endosulfan	U 10 - U 25	---	0/5	1
96	beta-endosulfan	U 10 - U 25	---	0/5	1
97	endosulfan sulfate	U 10 - U 25	---	0/5	1
98	endrin	U 10 - U 25	---	0/6	1
99	endrin aldehyde	U 10 - U 25	---	0/5	1
100	heptachlor	U 10 - U 25	---	0/6	1
101	heptachlor epoxide	U 10 - U 25	---	0/6	1
102	alpha-HCH	U 10 - U 25	---	0/6	1
103	beta-HCH	U 10 - U 25	---	0/6	1
104	delta-HCH	U 10 - U 25	---	0/6	1
105	gamma-HCH (lindane)	U 10 - U 25	---	0/6	1
113	toxaphene	U 10	---	0/2	1
PCBs					
xx	Total PCBs (primarily 1254/1260)	3.1 - U 20	1.8 - 12	7/19	1,2,3,4,6,7
Volatile Compounds					
85	tetrachloroethene	U 4.1 - U 16	---	0/8	2,3
38	ethylbenzene	U 4.1 - U 16	---	0/8	2,3

[a] Number indicates U.S. EPA priority pollutant number. HSL indicates Hazardous Substance List compound.

[b] Reference sites:

1. Carr Inlet	4. Case Inlet	7. Nisqually Delta
2. Samish Bay	5. Port Madison	
3. Dabob Bay	6. Port Susan	

[c] An anomalously high phenol value of 1,800 ug/kg dry weight was found at one Carr Inlet station. For the purposes of reference area comparisons, this value has been excluded.

[d] Mean calculated using 0.00 for undetected values.

[e] Mean calculated using the reported detection limit for undetected values.

References:

(Site 1)	This report; Mowrer et al. (1977).
(Site 2)	Battelle (1985).
(Site 3)	Battelle (1985); Prahl and Carpenter (1979).
(Site 4)	Malins et al. (1980); Mowrer et al. (1977).
(Site 5)	Malins et al. (1980).
(Site 6)	Malins et al. (1981).
(Site 7)	Barrick and Prahl (in prep); Mowrer et al. (1977).

TABLE 3.10. COMPARISON OF THE RANGE IN ELEVATIONS ABOVE REFERENCE (EAR) FOR ORGANIC CONTAMINANTS OF CONCERN IN SURFACE SEDIMENTS FROM COMMENCEMENT BAY

	Elevation Above Reference[a]			Areas Where Sediments Exceeded 10x Threshold[c]
	Range	Median	Threshold[b]	
phenol	0.1 - 57	3.4	1.7	HY,BL,SP, MD,CI
2-methylphenol	0.1 - 14	0.38	1.0[d]	SP,CI,RS
4-methylphenol	0.08 - 7200	8.3	1.6[d]	ALL SP
2,4-dimethylphenol	0.07 - 31	1.5	1.5[d]	RS
pentachlorophenol	0.01 - 26	1.5	1.5[d]	BL,MD
LMW aromatic hydrocarbons[e]	1.1 - 570	36.	10.	RS,CI,HY,MD, SI,SP
HMW aromatic hydrocarbons[f]	1.0 - 450	59.	6.4	ALL HY
chlorinated benzenes[g]	0.1 - 64	3.4	6.5	none HY
chlorinated butadienes[h]	0.03 - 1100	2.8	1.6[d]	HY,BL
total phthalates[i]	0.01 - 36	1.9	3.4	HY
total PCBs[j]	0.5 - 330	11	3.6	HY,RS
2-methylnaphthalene	0.3 - 330	44.	4.0	ALL RS
benzyl alcohol	1.0 - 50	2.3	1.0[d]	HY,CI,SP
benzoic acid	0.01 - 55	0.17	2.0	BL
dibenzofuran	0.3 - 540	30.	1.0	ALL RS
n-nitrosodiphenylamine	0.07 - 150	1.2	1.4[d]	RS,BL,CI,HY, SI
tetrachloroethene	1.0 - 21	1.0	1.0[k]	HY
ethylbenzene	1.0 - 5	1.0	1.0[k]	none HY
total xylenes	1.0 - 8	1.0	1.0[k]	none HY

[a] Dry-weight concentration in Commencement Bay sediments divided by the average concentration measured in six Carr Inlet reference sediments.

[b] The threshold EAR is defined as the ratio of the maximum reference sediment concentration in Puget Sound divided by the average for six Carr Inlet reference sediments. Above the threshold EAR, the dry-weight concentration of a Commencement Bay sediment contaminant would exceed the maximum concentration (or detection limit) reported for any Puget Sound reference site listed in Table 3.9.

TABLE 3.10. (Continued)

[c] The contaminant EAR in sediment from at least one station in each area listed exceeded the threshold level by an order of magnitude. Sediments in underlined areas had the highest observed values. "ALL" indicates that at least some sediment samples in all areas exceeded the threshold by an order of magnitude. "None" indicates that no sediment values exceeded 10x threshold; the area with the highest value is still listed.

[d] Compound has not been detected in any Puget Sound reference area to date. The method detection limit has been used for a threshold value.

[e] Low molecular weight (LMW) aromatic hydrocarbons (1-3 rings) include naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene.

[f] High molecular weight (HMW) aromatic hydrocarbons (4-6 rings) include fluoranthene, pyrene, benzo(a)anthracene, chrysene, total benzofluoranthenes-benzo(a)pyrene, indeno(1,2,3-c,d)pyrene, dibenzo(a,h)anthracene, and benzo-(g,h,i)perylene.

[g] Chlorinated benzenes include 1,3-dichlorobenzene, 1,4-dichlorobenzene, 1,2-dichlorobenzene, 1,2,4-trichlorobenzene, and hexachlorobenzene.

[h] Chlorinated butadienes include tri-, tetra-, and pentachlorobutadiene isomers, and hexachlorobutadiene.

[i] Phthalates include dimethyl, diethyl, di-n-butyl, butylbenzyl, bis(2-ethylhexyl), and di-n-octyl phthalates.

[j] Total PCBs is the sum of the detected Aroclors, typically Aroclor 1254 and 1260.

[k] Reference data not available; value is based on the method detection limit of 10 ug/kg (dry weight). These volatile compounds were undetected at over 20 Commencement Bay sites.

3.1.5 Prioritization of Areas Based on Sediment Contamination

To prioritize problem areas according to the steps outlined as part of the Commencement Bay Decision-Making Approach (Tetra Tech 1984a), the extent of sediment contamination was examined on three spatial scales: areas (waterways and the Ruston-Pt. Defiance Shoreline), segments within areas, and individual stations. Most inorganic and organic contaminants of concern (Tables 3.4 and 3.10) were distributed heterogeneously in Commencement Bay sediments. The following sections provide a description of how study area segments were defined for use in data analysis and a discussion of the results of spatial correlation analyses used to define groups of chemicals having similar sources or fates. Changes in concentrations of individual or groups of chemicals are then examined among study areas, segments, and chemical "hotspots" within segments to prioritize sediments by their level and spatial extent of contamination.

3.1.5.1 Definition of Study Area Segments--

Commencement Bay study areas were divided into twenty segments as shown in Figure 3.6 and summarized in Table 3.11. The major reason for defining segments was to provide a means of reporting major chemical, sediment toxicity, and biological gradients within areas that sometimes contained dozens of stations in various arrays. Hence, small areas such as Sitcum, Milwaukee, St. Paul, and Middle Waterways were not further divided. Boundaries of segments within large areas were generally established to define major zones of varying chemical contamination. Contamination from one group of chemicals sometimes extended well past a segment boundary defined according to a zone of contamination for other chemicals.

At a minimum, each segment was required to contain at least three stations (except segment CIS2 comprising the isolated Wheeler-Osgood branch of City Waterway). Segments were also required to contain at least one station for which complementary biolgical and sediment toxicity data were available (except segment BLS4 located in deep water outside of Blair Waterway). Average concentrations of chemicals within segments are used in later discussion to evaluate trends in chemical concentrations along areas. "Hotspots" of chemical contamination are evaluated at individual stations when chemical gradients are apparent within segments.

3.1.5.2 Spatial Correlations Among Sediment Contaminants--

Linear correlation analyses were conducted to define groups of chemicals having similar sources or depositional fates. All tests were based on Spearman's correlation test (SPSS 1984). Covarying chemical groups were defined as those showing a high degree of correlation in tests with the entire data set (maximum of n=148, including replicate analyses), with Hylebos Waterway data only (n=45), with Blair Waterway data only (n=38), or with City Waterway data only (n=15). Subsets of the entire data set were examined to ensure that apparent correlations were not artifacts of extreme concentrations in a single area and to discriminate local distribution patterns within the larger waterways. Scatterplots of the concentrations of chemicals showing strong correlations, and those having unexpectedly weak correlations, were examined for outliers. Correlations of metals

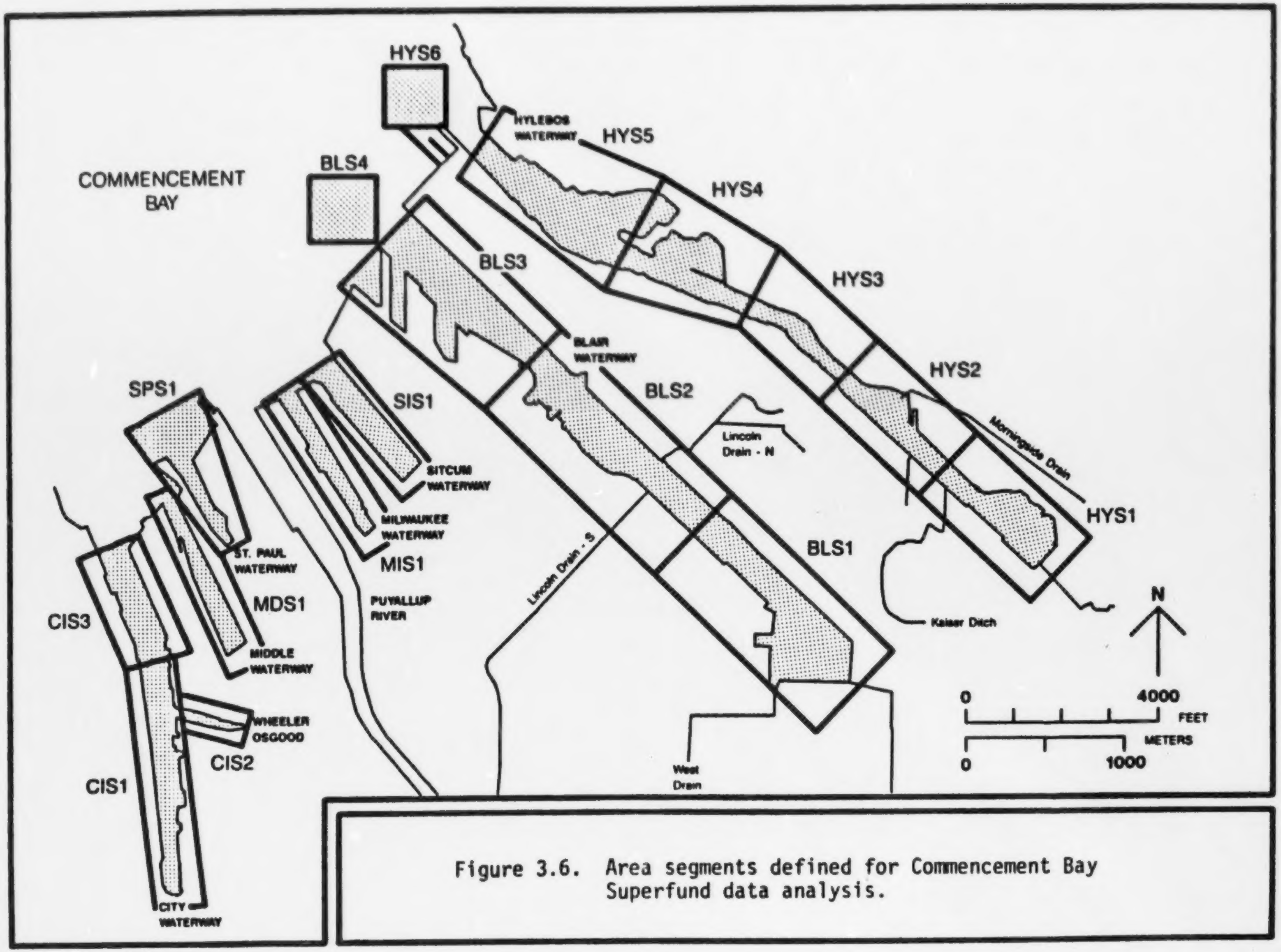

HYS6
BLS4
COMMENCEMENT BAY
HYLEBOS WATERWAY
HYS5
HYS4
HYS3
HYS2
HYS1
Morningside Drain
Kaiser Ditch
BLS3
BLAIR WATERWAY
BLS2
BLS1
Lincoln Drain - N
Lincoln Drain - S
West Drain
SPS1
SIS1
SITCUM WATERWAY
MILWAUKEE WATERWAY
MIS1
PUYALLUP RIVER
ST. PAUL WATERWAY
MDS1
MIDDLE WATERWAY
CIS3
WHEELER OSGOOD
CIS2
CIS1
CITY WATERWAY
N
0
4000
FEET
METERS
0
1000

Figure 3.6. Area segments defined for Commencement Bay Superfund data analysis.

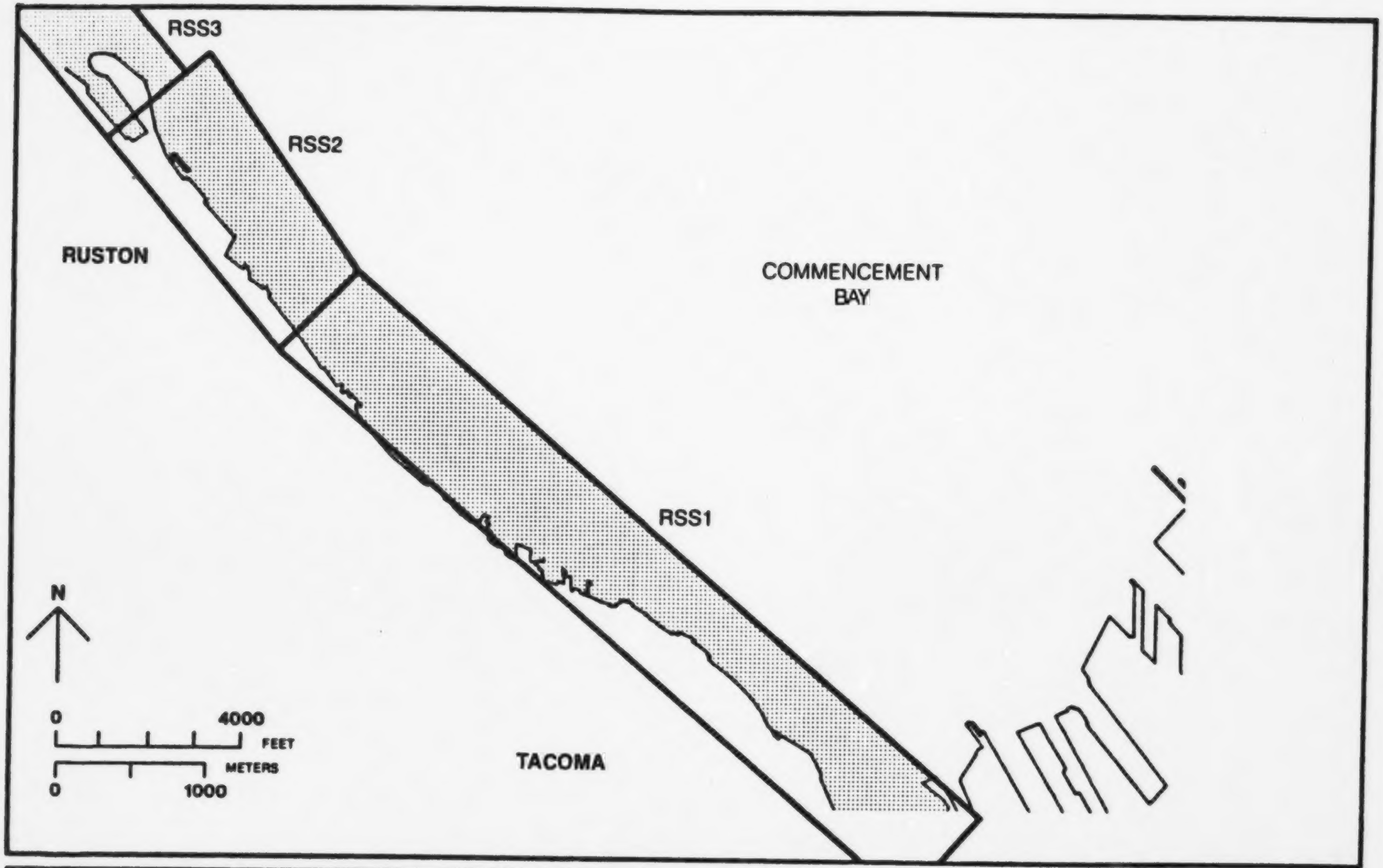

RSS3
RSS2
RSS1
RUSTON
COMMENCEMENT BAY
TACOMA
N
0
4000
FEET
METERS
0
1000

Figure 3.6. (Continued)

TABLE 3.11. COMMENCEMENT BAY AREA SEGMENTS USED FOR DATA ANALYSIS

Segment	**Relevant Sediment Stations**
HYLEBOS WATERWAY:	
HYS1 - Hylebos Upper Turning Basin	HY-11, HY-12, HY-13, HY-14, HY-15, HY-16, HY-17, HY-18, HY-19 **[9 stations including 3 biology]**
HYS2 - Hylebos Lower Turning Basin	HY-20, HY-21, HY-22, HY-23, HY-24, HY-25, HY-26 **[7 stations including 3 biology]**
HYS3 - Hylebos off Lincoln Ave	HY-01, HY-27, HY-28, HY-29, HY-30, HY-31 **[6 stations including 1 biology]**
HYS4 - Hylebos above 11th Street	HY-32, HY-33, (HY-34), HY-35 **[4 stations including 1 biology]**
HYS5 - Lower Hylebos Waterway	HY-02, HY-03, HY-36, HY-37, HY-38, HY-39, HY-40, HY-41, HY-42, HY-43, HY-44, HY-45, HY-46, HY-47, HY-48 **[15 stations including 5 biology]**
HYS6 - Outside Hylebos Waterway	HY-49, HY-50, HY-51, CB-11 **[4 stations including 1 biology]**
BLAIR WATERWAY	
BLS1 - Blair Upper Turning Basin	BL-01, BL-11, BL-12, BL-13, BL-14, BL-15, B-02, B-11, B-12 **[9 stations including 3 biology]**
BLS2 - Blair Waterway Lincoln to 11th	BL-02, BL-16, BL-17, BL-18, BL-19, BL-20, BL-21, BL-22, BL-23, BL-24, BL-25, BL-26, B-03, B-04, B-07, B-14, B-15 **[17 stations including 5 biology]**
BLS3 - Lower Blair Waterway	BL-03, BL-04, BL-27, BL-28, BL-29, BL-30, BL-31, BL-32, B-09, B-10, B-17, B-18 **[12 stations including 4 biology]**
BLS4 - Outside Blair Waterway	CB-12, CB-13, CB-14 **[3 stations; NO biology stations]**

TABLE 3.11. (Continued)

SITCUM WATERWAY (SIS1):	SI-11, SI-12, SI-13, SI-14, SI-15 **[5 stations including 3 biology]**
MILWAUKEE WATERWAY (MIS1):	MI-01, MI-11, MI-12, MI-13, MI-14, MI-15 **[6 stations including 3 biology]**
ST. PAUL WATERWAY (SPS1):	SP-11, SP-12, SP-13, SP-14, SP-15, SP-16 **[6 stations including 5 biology]**
MIDDLE WATERWAY (MDS1):	MD-01, MD-11, MD-12, MD-13 **[4 stations including 1 biology]**
CITY WATERWAY:	
CIS1 - City Waterway above 11th St.	CI-01, CI-03, CI-11, CI-12, CI-13, CI-14, CI-15, CI-17, CI-18 **[9 stations including 3 biology]**
CIS2 - Wheeler-Osgood Waterway	CI-02, CI-16 **[2 stations including 1 biology]**
CIS3 - City Waterway below 11th St.	CI-19, CI-20, CI-21, CI-22 **[4 stations including 2 biology]**
RUSTON-PT. DEFIANCE SHORELINE:	
RSS1 - Eastern Shoreline	RS-02, RS-04, RS-11, RS-12, RS-13, RS-14, RS-15 **[7 stations including 3 biology]**
RSS2 - Shoreline at ASARCO outfalls	RS-03, RS-16, RS-17, RS-18, RS-19, RS-20, RS-21 **[7 stations including 3 biology]**
RSS3 - Pt. Defiance	RS-22, RS-24 **[2 stations including 2 bioassay only]**

and organic compounds were tested for concentrations normalized to dry sediment weight, to total organic carbon (TOC), and to the total percent of fine-grained material.

The strongest correlations for most substances were found when concentrations were normalized to TOC (especially organic compounds) or percent fine-grained material (especially metals) (see Section 3.1.2). Correlation coefficients for organic and inorganic chemicals having moderate to strong intercorrelations (i.e., r >0.7 to 1.0) are summarized in Appendix II. Inorganic chemicals of concern with at least moderate spatial correlations (i.e., r >0.7) among chemical pairs in the total data set and in data subsets for Hylebos and City Waterways were:

- Copper, lead, and zinc (r=0.85 to 0.98, n=143 total data set; r=0.73 to 0.88, n=45 Hylebos Waterway; r=0.77 to 0.95, n=15 City Waterway; all concentrations normalized to percent fine-grained material).

Some strong correlations of metal concentrations in the entire data set resulted simply from the inclusion of high concentration values for most metals at stations off the ASARCO outfalls on the Ruston-Pt. Defiance Shoreline. Copper, lead, and zinc were the only metals of concern whose distributions appeared to be well-correlated within most study areas (i.e., even when Ruston-Pt. Defiance values were excluded), although their correlation among Blair Waterway samples was poor (i.e., r <0.4; n=38). These three metals are treated in later sections as one group for ease of analysis. Compositional variations among the metals in areas such as Blair Waterway will be discussed as appropriate.

Major organic compound groups showing the best correlations among compound pairs in the entire data set were:

- Chlorinated butadiene congeners (tri-, tetra-, penta-, and hexachlorinated butadienes; r=0.97 to 1.0; TOC normalized concentrations; n=136)

- Chlorinated benzenes (r=0.55 to 0.98; TOC normalized concentrations; n=144)

- Low molecular weight aromatic hydrocarbons (r=0.50 to 0.94; TOC normalized concentrations; n=144)

- High molecular weight aromatic hydrocarbons (r=0.59 to 0.94; TOC normalized concentrations; n=144).

Correlations were often strengthened when data subsets were examined (e.g., intercorrelations among low molecular weight aromatic hydrocarbons in City Waterway ranged from r=0.83 to 0.98; n=15). Weaker correlations over the entire study area are attributed to changing compositions of chemicals emitted by different sources among study areas. Distributions of three of the chlorinated benzenes (i.e., 1,2,4-trichlorobenzene, hexachlorobenzene, and 1,4-dichlorobenzene) were well-correlated with the distribution of chlorinated butadienes (i.e., r ≥0.89). There was also an overlap in the distribution of low and high molecular weight aromatic hydrocarbons, especially among 3- and 4-ring aromatic hydrocarbons.

Compounds with correlations at the lower end of the range reported for compound groups were often present in low concentration (e.g., dibenzo(a,h)-anthracene in the high molecular weight aromatic hydrocarbon group). Such compounds are subject to greater analytical variability than other compounds of the defined groups. Other compounds with lower correlations in these groups apparently have additional sources not shared by the other components (e.g. 1,3-dichlorobenzene in the chlorinated benzene group). In the latter case, the defined groups are used in later sections only to indicate the magnitude of contamination by the group; individual components of the group are analyzed separately during source determinations in defined problem areas.

Nonpriority pollutant hazardous substance list compounds and additional tentatively identified compounds with concentration distributions that tended to correlate with those of the chemical groups already defined include:

- Dibenzofuran, and tentatively identified compounds including dibenzothiophene, 2-methylnaphthalene, methylphenanthrenes, and biphenyl with aromatic hydrocarbons (especially 1- to 3-ring compounds; r=0.66 to 0.89; TOC normalized concentrations; n=121)

- Pentachlorocyclopentane (isomer; tentative identification) with 1,2,4-trichlorobenzene, hexachlorobenzene, 1,4-dichlorobenzene, and chlorinated butadienes (r=0.89 to 0.98; TOC normalized concentrations; n=123).

Concentrations of some chemicals showed strong correlations only within a single area (e.g., Hylebos Waterway). Those combinations of inorganic and organic chemicals with strictly local importance are discussed when individual problem areas are reviewed in Section 6.

3.1.5.3 Relative Magnitude of Contamination Among Study Areas--

Concentrations of the chemicals of concern listed in Tables 3.4 and 3.10 (i.e., those found at concentrations that exceed Puget Sound reference conditions) varied in some cases over five orders of magnitude in Commencement Bay surface sediments. Concentrations (DW) of the four inorganic and six organic contaminants listed in Table 3.12 exceeded 1,000 times reference conditions at individual Commencement Bay stations. Concentrations of metals were elevated to this degree only in sediments at three stations directly off the three major ASARCO outfalls on the Ruston-Pt. Defiance Shoreline. Concentrations of arsenic and antimony averaged over all stations in segment RSS2 (Figure 3.6) along the Ruston-Pt. Defiance Shoreline were also elevated over 1,000 times reference conditions.

Organic compound concentrations exceeded 1,000 times reference conditions only in sediments from selected stations in Upper and Lower Hylebos Waterway, from stations directly off the main Champion International outfall in St. Paul Waterway, and from a single station directly off the main ASARCO outfall

TABLE 3.12. SUMMARY OF CHEMICALS WITH ELEVATIONS ABOVE REFERENCE (EAR) GREATER THAN 1,000X IN SEDIMENTS FROM COMMENCEMENT BAY

Chemicals Exceeding 1,000x Reference	Station
ORGANIC COMPOUNDS:	
benzo(a)pyrene	HY-22
4-methylphenol	SP-14
2-methyoxyphenol	SP-14,-15
phenanthrene	RS-18
trichlorobutadienes	HY-43,-46,-47
tetrachlorobutadienes	HY-46
METALS:	
antimony	RS-17,-18,-21
arsenic	RS-17,-18,-21
copper	RS-17,-18,-21
mercury	RS-18

Chemicals Exceeding 1,000x Reference[a]	Area or Segment
ORGANIC COMPOUNDS:	
4-methylphenol	St. Paul Waterway
2-methoxyphenol	St. Paul Waterway
METALS:	
antimony	RSS2
arsenic	RSS2

[a] Concentration averaged over all stations in the area or segments indicated.

on the Ruston-Pt. Defiance Shoreline. Concentrations of two phenolic compounds averaged over all stations in St. Paul Waterway exceeded 1,000 times reference conditions.

Twenty-eight chemicals or chemical groups with sediment concentrations (DW) at one or more stations that were elevated between 100 and 1,000 times reference conditions at Carr Inlet are listed in Table 3.13. Station locations are also indicated. All metals of concern except nickel were found at these levels, primarily at stations along the Ruston-Pt. Defiance Shoreline. Similar elevations in concentrations of organic compounds were more widespread throughout the Commencement Bay study area (Table 3.13).

Sediment concentrations between 100 and 1,000 times Carr Inlet reference conditions were also observed for 17 of these 28 substances after averaging over multiple stations in an area or segment (Table 3.14). For metals, such high average elevations were found only along the Ruston-Pt. Defiance Shoreline, and in segments RSS2 and RSS3 of the shoreline. For organic compounds, such high average elevations were found in all study areas except Blair Waterway and the Ruston-Pt. Defiance Shoreline (Table 3.14). The potential relationships among these contaminants and observed sediment toxicity and biological effects are discussed in Section 4.

Distributions of eight major chemicals or chemical groups of concern among Commencement Bay study areas are shown in Figures 3.7-3.14. The distributions of these chemicals give a perspective of the major zones of contamination in Commencement Bay based on data collected under this investigation. Distributions of the remaining chemicals of concern are addressed in discussions of problem areas (Section 6). Each figure has two key features. First, a pair of graphs is presented for each contaminant or contaminant group. The upper graph of each pair shows the average magnitude of contamination expressed as the elevation above reference (EAR) concentrations measured at Carr Inlet. For example, a concentration of 100 ug/kg in the study area relative to a concentration of 20 ug/kg in Carr Inlet would result in an EAR of 5. The same data are presented in the lower graph of each pair, but each average EAR has been recalculated as a percentage of the largest average EAR observed among Commencement Bay areas. This later data format is useful in visually demonstrating the relative contamination among areas.

Second, to enable a comparison of the relative magnitude of contaminant concentrations in sediments containing differing amounts of fine-grained material and organic carbon, EAR reported in the figures are based on ratios of sediment concentrations normalized three different ways. The first bar shown for each area represents the magnitude of EAR calculated using study area and reference area concentrations normalized to total dry weight of sediment. EAR represented by the second bar are based on a ratio of concentrations normalized to the weight of the fine-grained fraction only. The third bar represents the EAR based on concentrations normalized to the weight of the total organic carbon in each sample.

For example, in Figure 3.7 the sum of copper, lead, and zinc dry-weight concentrations averaged over all sediments collected from the Ruston-Pt. Defiance Shoreline is 120 times higher (i.e., EAR=120) than the sum of the average dry-weight concentrations of these three metals in sediments

TABLE 3.13. SUMMARY OF CHEMICALS WITH ELEVATIONS ABOVE REFERENCE (EAR) BETWEEN 100 AND 1,000X IN SEDIMENTS FROM COMMENCEMENT BAY STATIONS

Chemicals >100x and <1,000x Reference	Station
ORGANIC COMPOUNDS:	
aromatic hydrocarbons (4-6 rings; non-alkylated)	BL-14; B-04; CI-01,02,03,11,12, CI-13,15,17,21,22; HY-12 through 26,33,36; MD-11,12; MI-11; RS-13,14,18,21; SI-11
aromatic hydrocarbons (1-3 rings; non-alkylated)	CI-01,02,11,12,15,17,21,22 HY-16,22,23; MD-11,12; RS-13,16,18,21; SI-14; SP-13,14
1,1'-biphenyl	RS-18
bis(2-ethylhexyl)phthalate	CI-12,13,15; HY-22
coprostanol	BL-04; CI-03,12; HY-03,41; MI-01; SI-14; SP-11
dibenzofuran	CI-11,15; HY-22; MD-11,12; RS-13,16, RS-18,21; SI-14; SP-13
dibenzothiophene	RS-18
1,2-dichlorobenzene	CI-16
isopimaradiene	BL-01,04,13,32; CI-03,12,17,20; HY-15,16,36,42,43,47; MD-12; MI-13,15; RS-04; SI-11,12; SP-11,12,14,15
kaur-16-ene [tentative id]	BL-04; CI-03,11,20; HY-01,03,12,14,15,16, 17,22,25,28,29,31,33,35,37,40,41,42,43,47 MD-01,12; MI-11,15; RS-04; SI-11,12,15; SP-11,12,14,15,16
1-methyl-2-(1-methylethyl benzene)	SP-14; RS-16; SI-11
2-methylnaphthalene	BL-16; CI-02,03,11,12,15,16,17,18,21,22; HY-22,26,36,39; MD-11,12; MI-12; RS-13,16,18,21; SI-14,15; SP-13,14
4-methylphenol	SP-13,14
2-methylphenanthrene	BL-01,04,24,32; CI-03,12,15,17 through 22 HY-14,15,16,17,22,30,31,34,36,43,45; MD-11,12,13; MI-11,13; RS-11,13,16,17, RS-19,21; SI-11,12,14,15; SP-11,12

TABLE 3.13. (Continued)

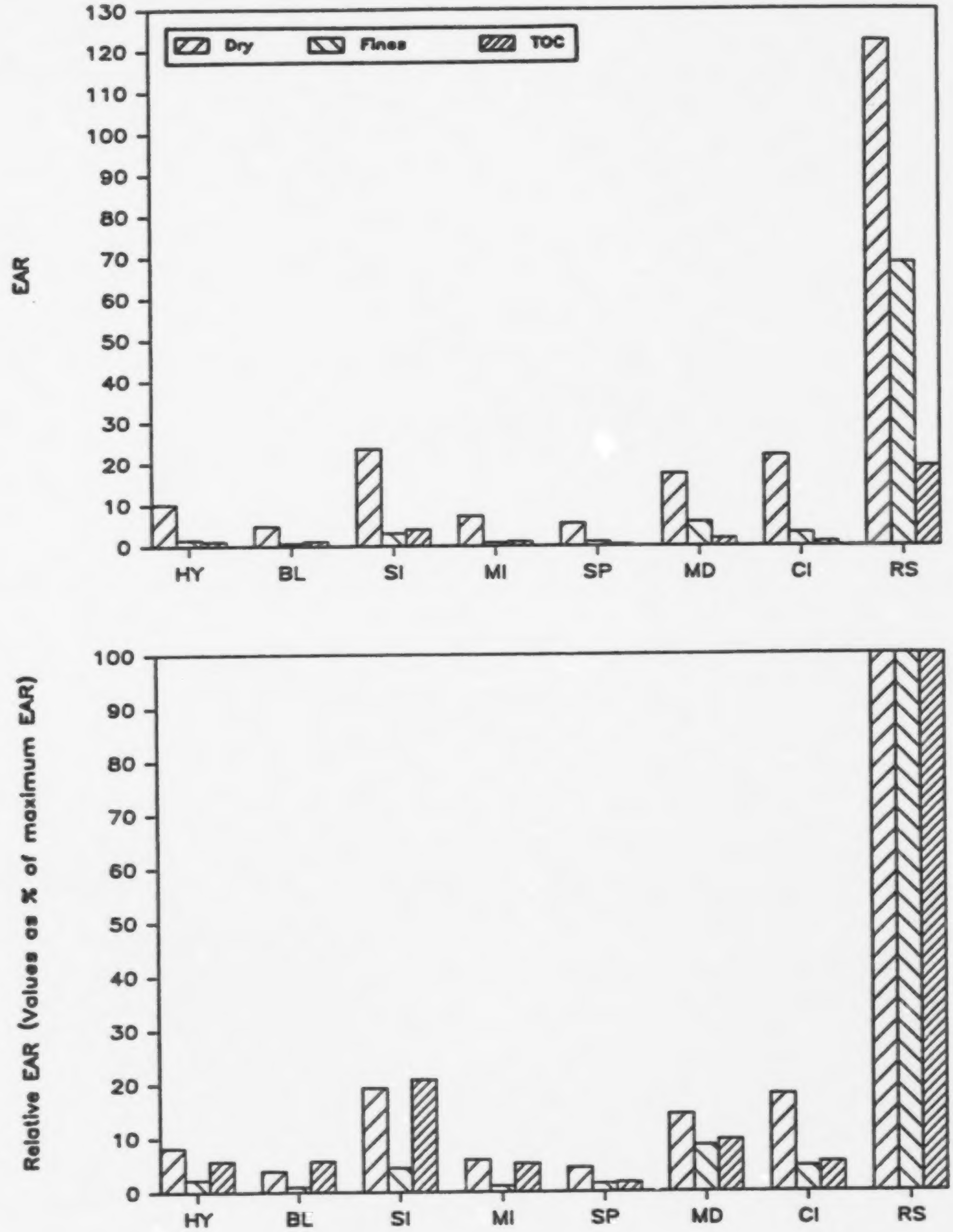
2-methylphenanthrene	RS-18; SP-14
1-methylphenanthrene	RS-18
1-methylpyrene	HY-16,17,22; RS-18
2-methylpyrene	CI-20; HY-15,16,21,36; RS-18
n-nitrosodiphenylamine	RS-18
Total chlorinated butadienes	HY-22,25,28,33,36,37, HY-39 through 43,45,47,48
Total PCBs	HY-03,22,23,27,42
METALS:	
antimony	HY-16; RS-19,24
arsenic	RS-19,24
cadmium	RS-17,18,21
copper	RS-19
lead	RS-17,18,19,21
mercury	RS-17,21
zinc	RS-17,18,21

TABLE 3.14. SUMMARY OF CHEMICALS WITH SEDIMENT ELEVATIONS ABOVE REFERENCE (EAR) BETWEEN 100 AND 1,000X AVERAGED OVER COMMENCEMENT BAY AREAS OR SEGMENTS

Chemicals >100x and <1,000x Reference	Waterway or Segment
ORGANIC COMPOUNDS:	
aromatic hydrocarbons (4-6 rings)	Hylebos Waterway and HYS1,HYS2 City Waterway and CIS1,CIS2,CIS3 RSS2
aromatic hydrocarbons (1-3 rings)	City Waterway and CIS1,CIS2,CIS3 Middle Waterway RSS2
bis(2-ethylhexyl)phthalate	City Waterway and CIS1,CIS2
isopimaradiene	HYS1 Sitcum Waterway St. Paul Waterway CIS3
kaur-16-ene [tentative id]	Hylebos Waterway and HYS1,HYS3,HYS5 Sitcum Waterway Milwaukee Waterway St. Paul Waterway Middle Waterway City Waterway and CIS1,CIS3
1-methyl-2-(1-methylethyl)benzene	St. Paul Waterway
2-methylnaphthalene	City Waterway and CIS1,CIS2,CIS3 Middle Waterway
1-methylpyrene	HYS1
2-methylpyrene	HYS1
2-methoxyphenol	Sitcum Waterway Milwaukee Waterway Middle Waterway City Waterway
total chlorinated butadienes	Hylebos Waterway and HYS4,HYS5

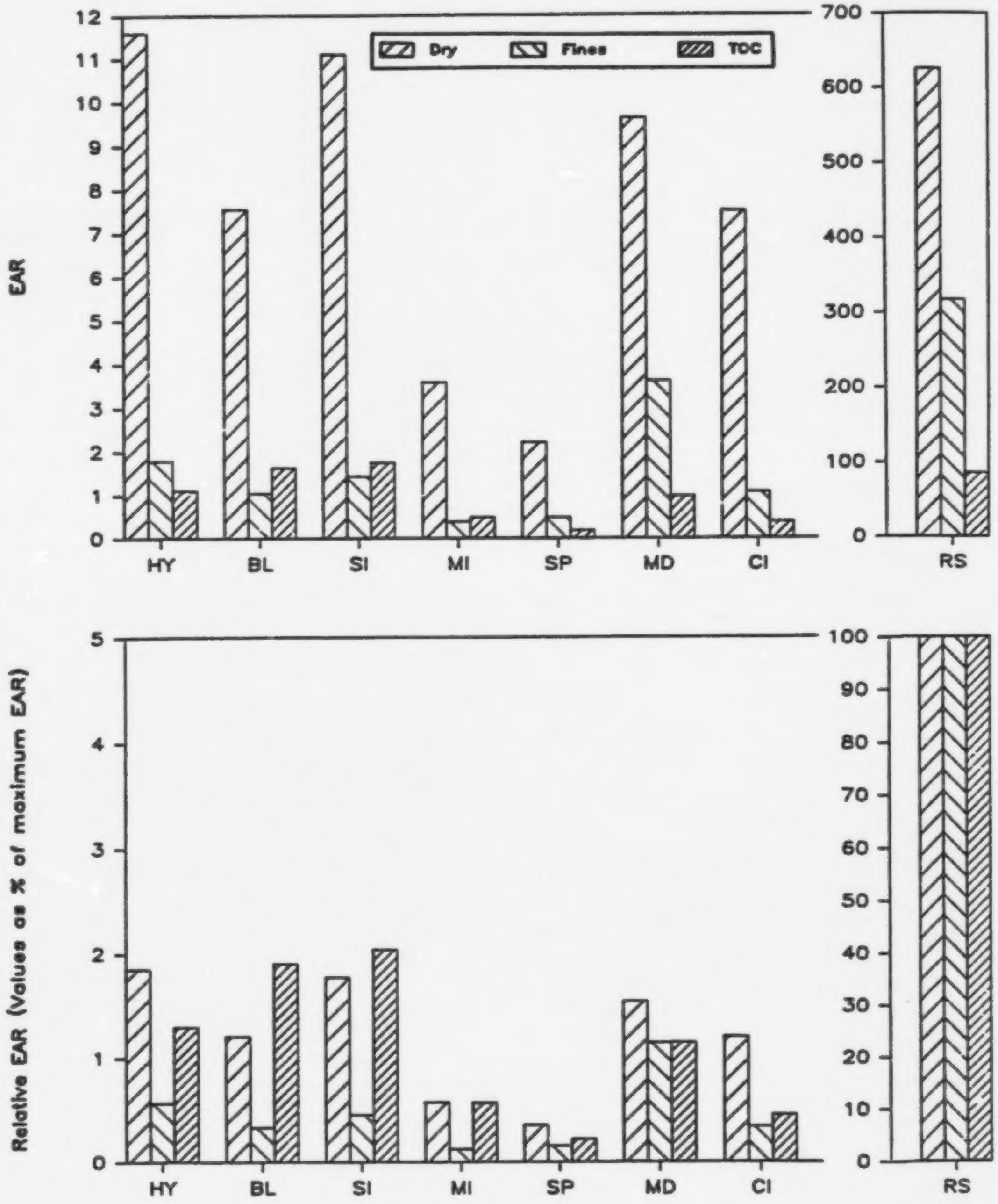
TABLE 3.14. (Continued)

total PCBs	HYS2
METALS:	
antimony	Ruston-Pt. Defiance and RSS3
arsenic	Ruston-Pt. Defiance and RSS3
copper	Ruston-Pt. Defiance and RSS2
lead	Ruston-Pt. Defiance and RSS2
mercury	Ruston-Pt. Defiance and RSS2



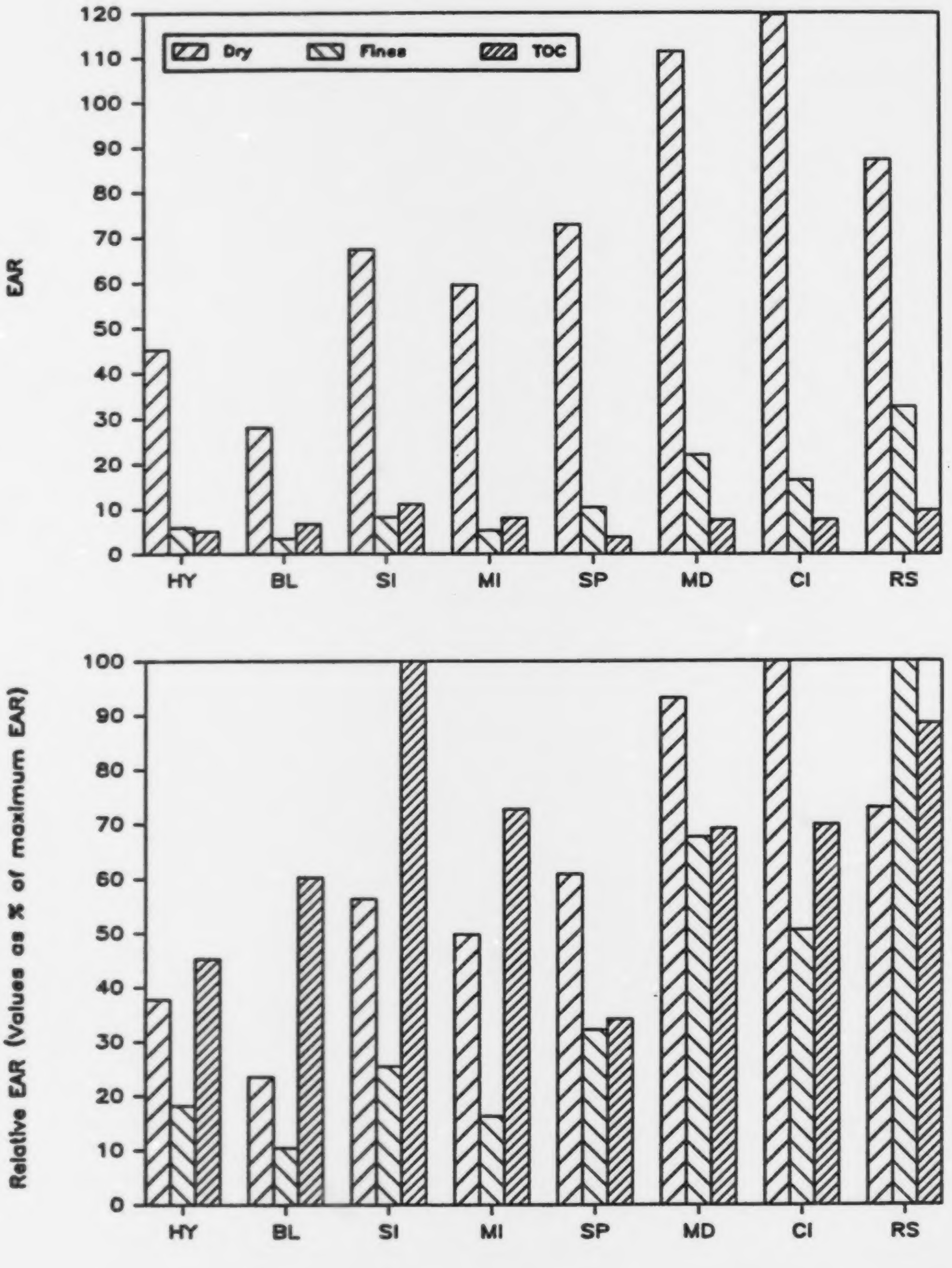
NOTE: Mean reference (µg/kg): 34 (DW); 360 (% fines): 11,000 (TOC)

Figure 3.7. Elevations above reference (EAR) for Pb, Cu, Zn in Commencement Bay study areas.



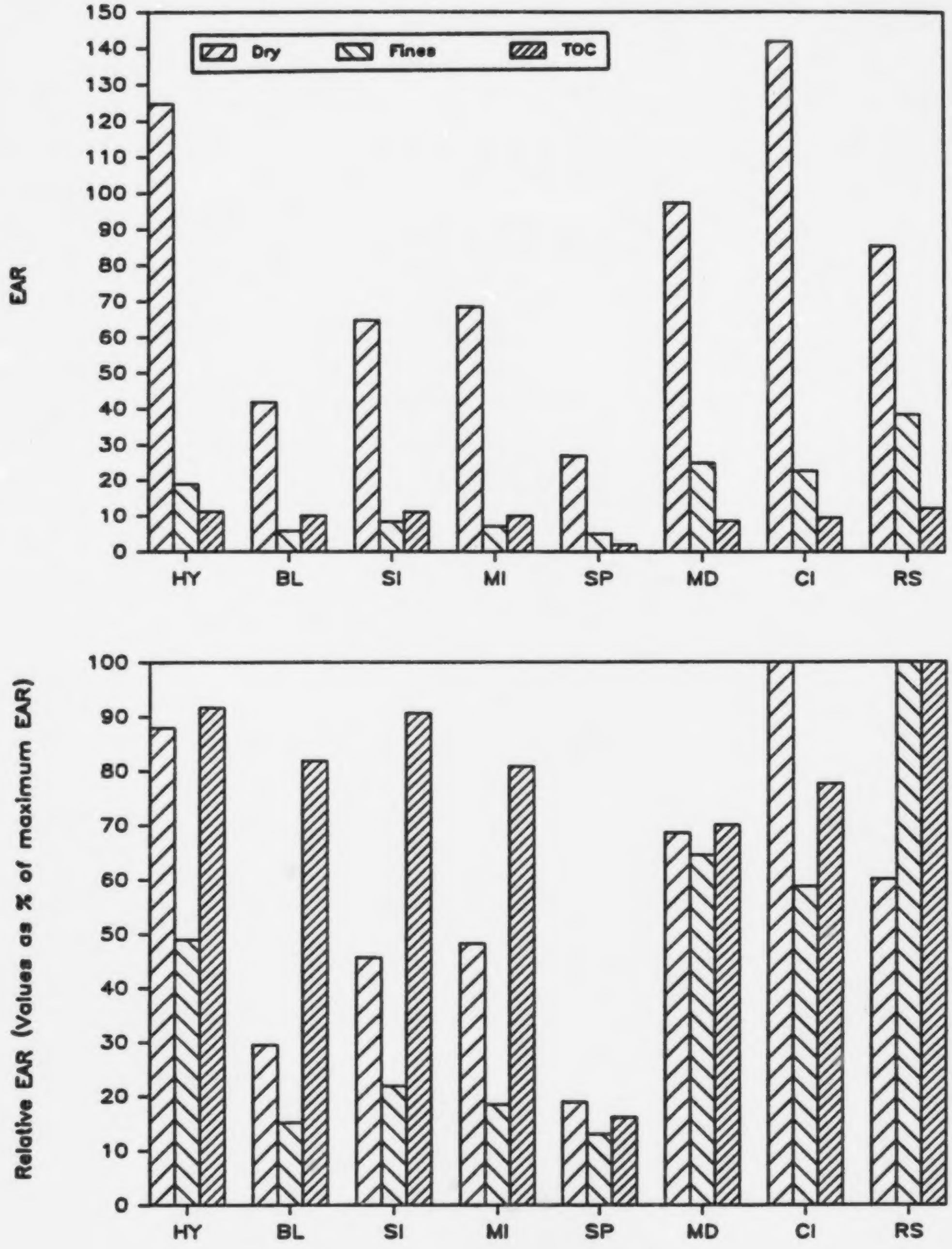
NOTE: Mean reference (µg/kg): 3.4 (DW); 35 (% fines): 1,100 (TOC)

Figure 3.8. Elevations above reference (EAR) for arsenic in Commencement Bay study areas.



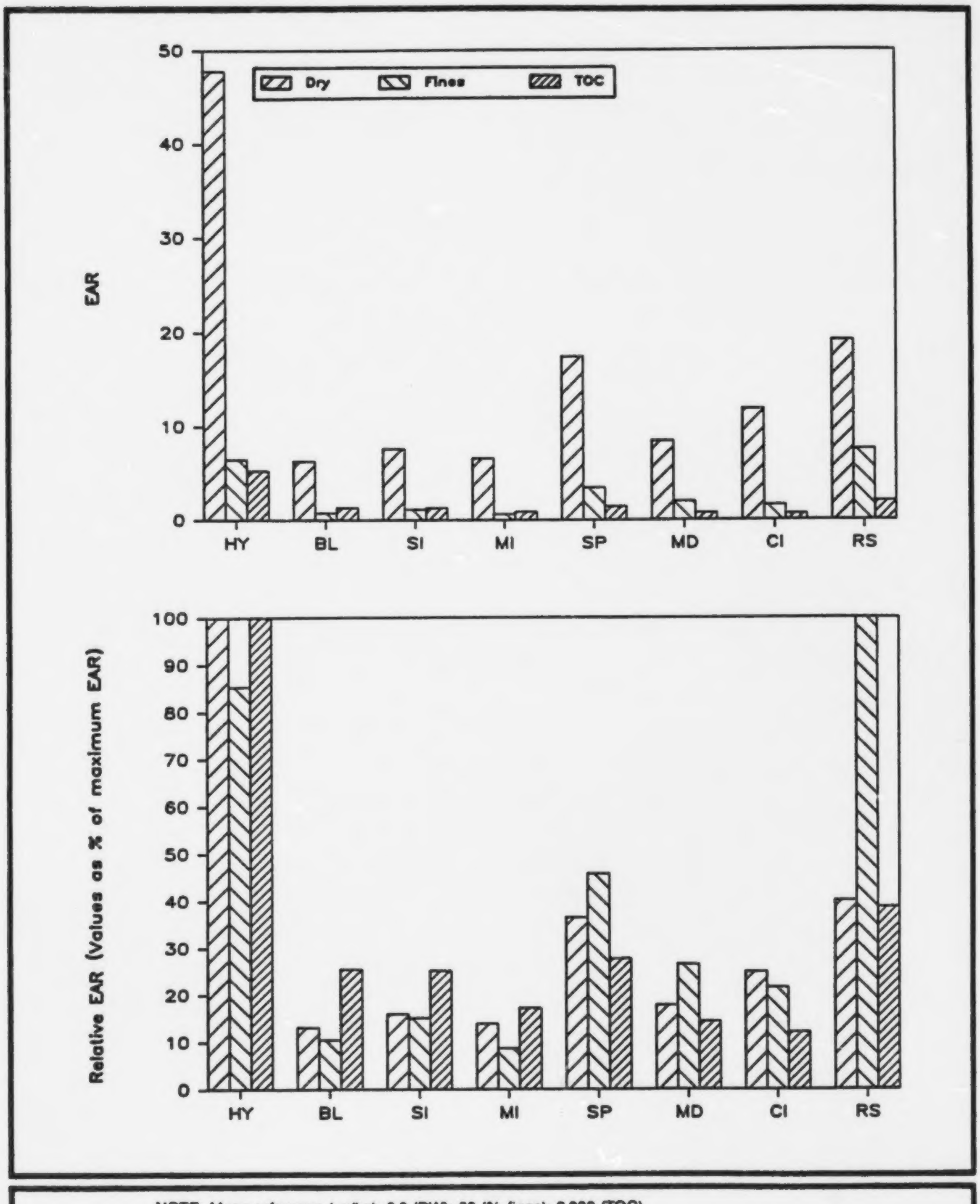
NOTE: Mean reference (µg/kg): 41 (DW); 450 (% fines): 12,000 (TOC)

Figure 3.9. Elevations above reference (EAR) for low molecular weight aromatic hydrocarbons in Commencement Bay study areas.



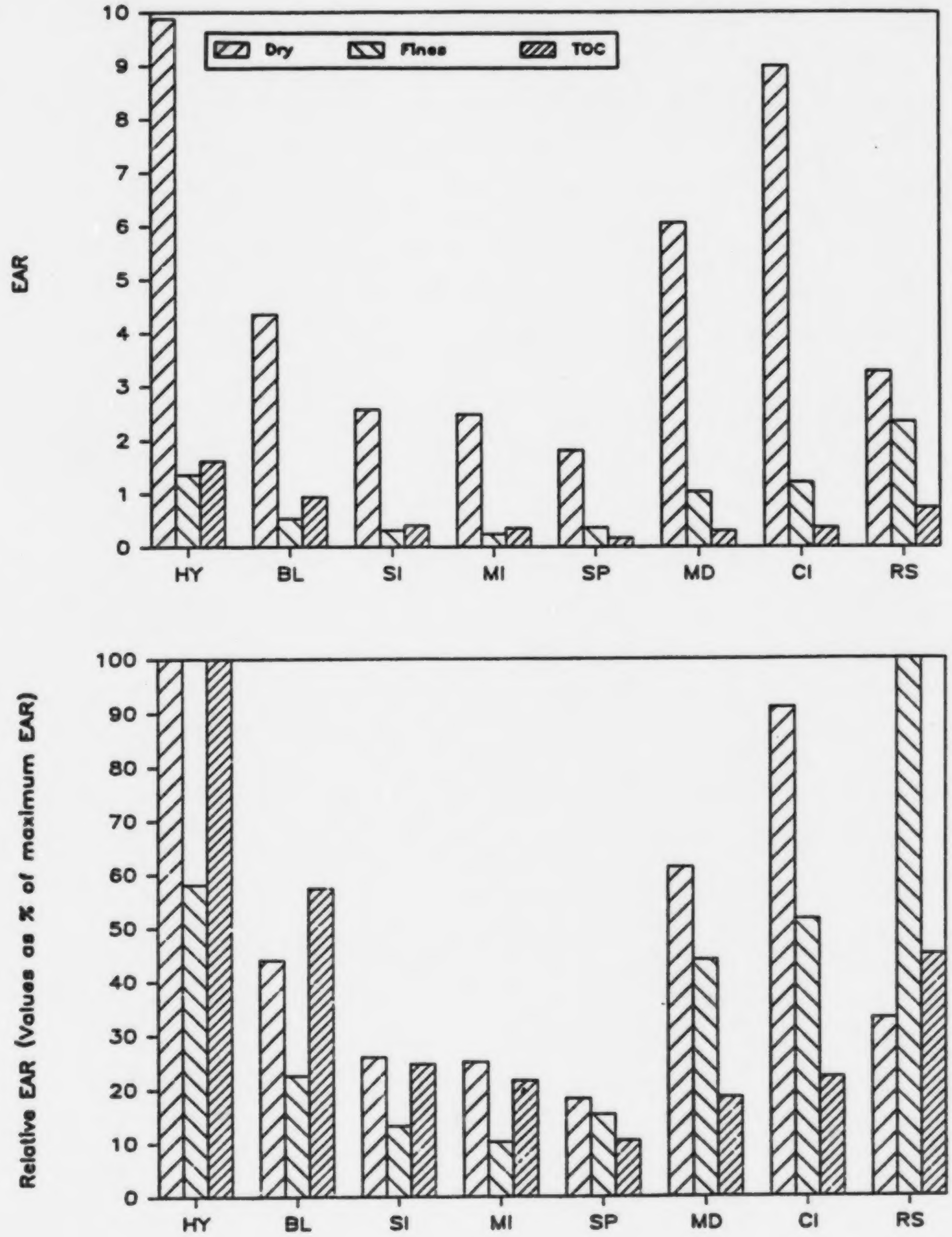
NOTE: Mean reference (µg/kg): 79 (DW); 830 (% fines): 24,000 (TOC)

Figure 3.10. Elevations above reference (EAR) for high molecular weight aromatic hydrocarbons in Commencement Bay study areas.



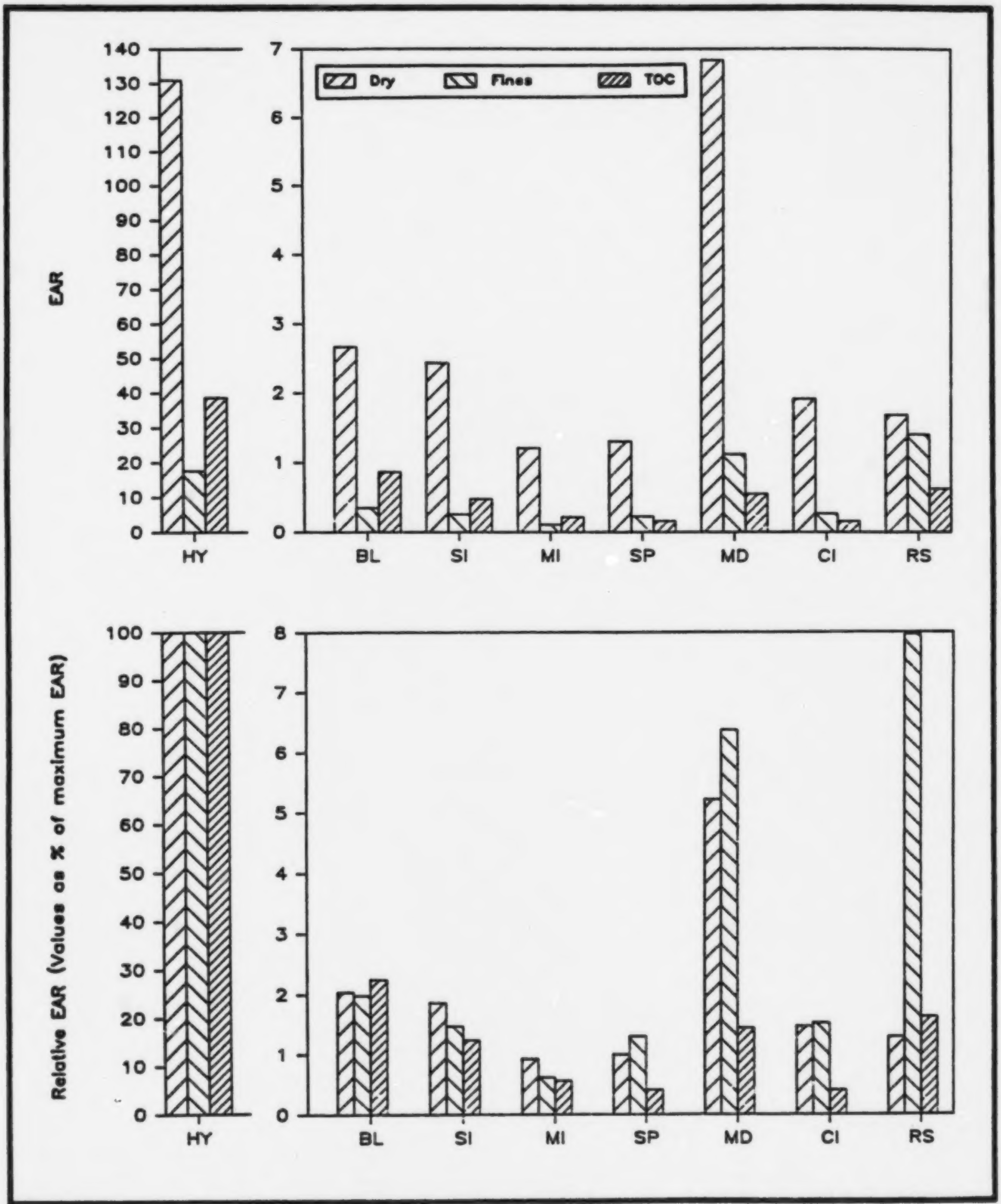
NOTE: Mean reference (μg/kg): 6.0 (DW); 68 (% fines): 2,000 (TOC)

Figure 3.11. Elevations above reference (EAR) for total PCBs in Commencement Bay study areas.



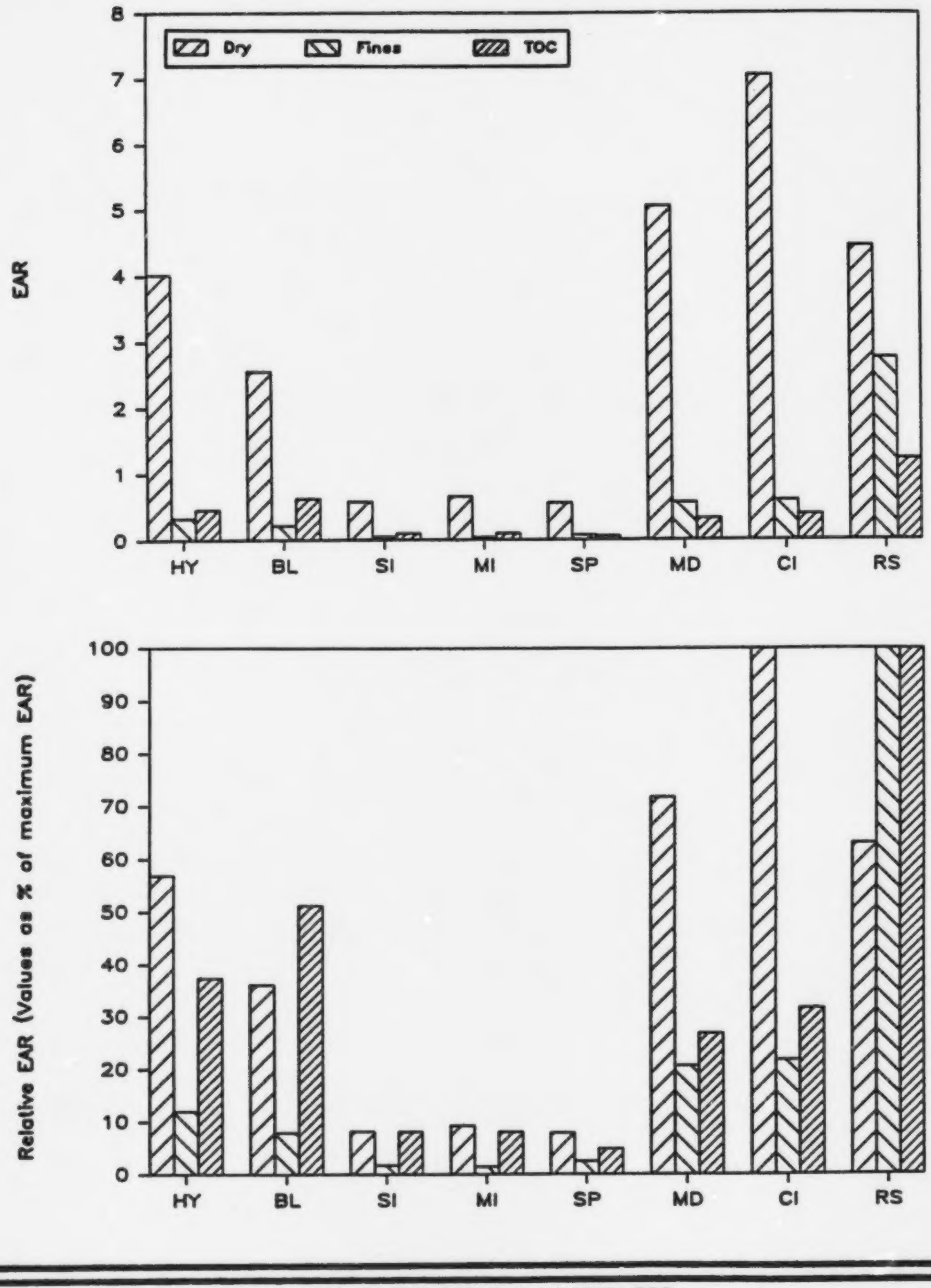
NOTE: Mean reference (µg/kg): 21 (DW); 250 (% fines): 7,400 (TOC)

Figure 3.12. Elevations above reference (EAR) for total chlorinated benzenes in Commencement Bay study areas.



NOTE: Mean reference (µg/kg): 62 (DW); 770 (% fines): 16,000 (TOC)

Figure 3.13. Elevations above reference (EAR) for total chlorinated butadienes in Commencement Bay study areas.



NOTE: Mean reference (µg/kg): 280 (DW); 5,000 (% fines): 88,000 (TOC)

Figure 3.14. Elevations above reference (EAR) for total phthalates in Commencement Bay study areas.

from Carr Inlet. When normalized to the total percent fine-grained material, the sum of average concentrations for copper, lead, and zinc in Ruston-Pt. Defiance Shoreline sediments is approximately 70 times higher than the average calculated for Carr Inlet sediments (i.e., EAR=70). The corresponding EAR on an organic carbon basis is 19. In general, the greatest variations among waterways were found for concentrations normalized to dry weight, and the smallest variations were found for concentrations normalized to organic carbon.

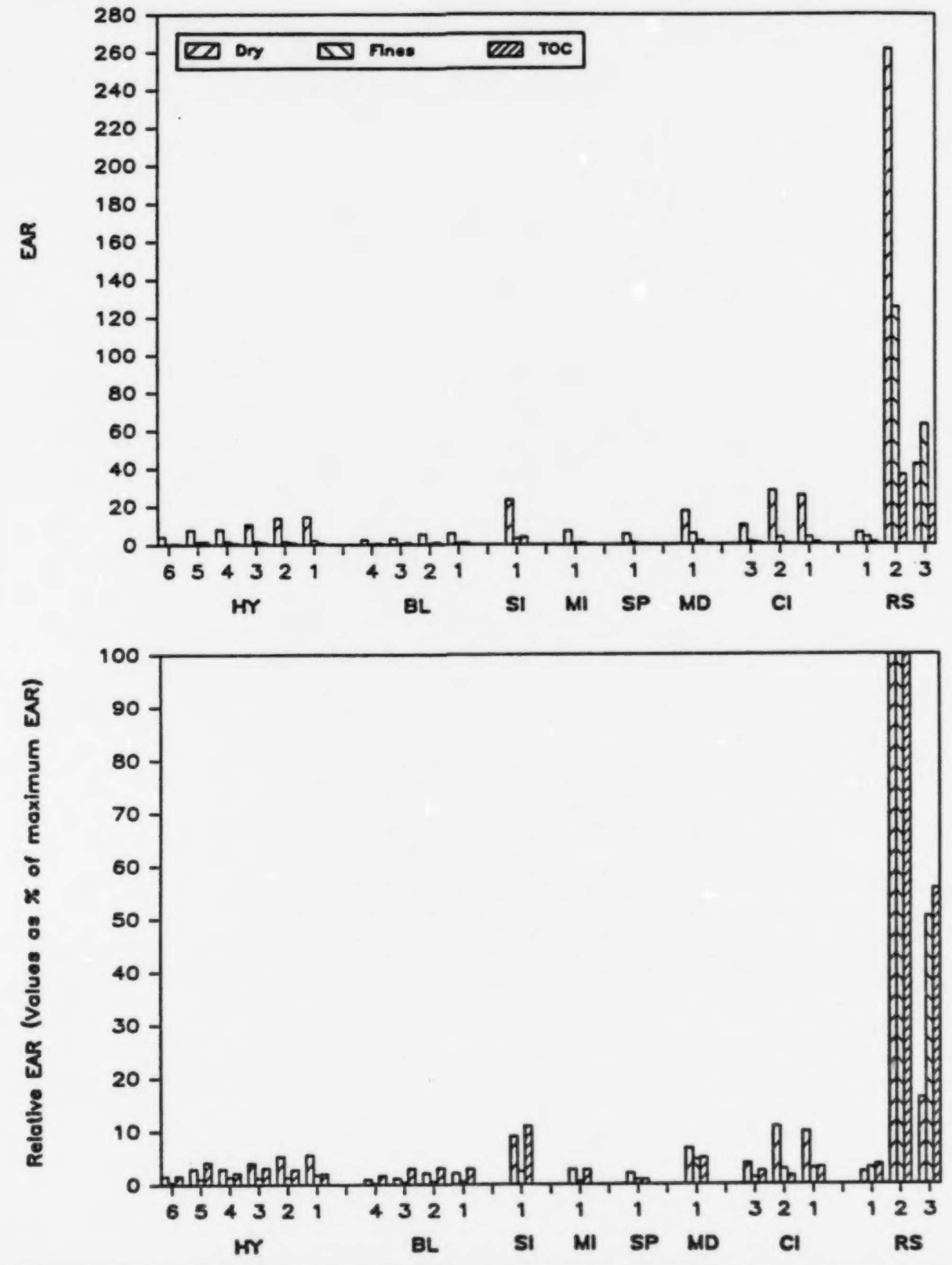
Data presented in Figures 3.7 and 3.8 show that the average metals contamination along the Ruston-Pt. Defiance Shoreline is 5-50 times higher than that in any other area, regardless of the method of normalization. This extreme elevation in one study area only is not seen for low and high molecular weight aromatic hydrocarbons (Figures 3.9 and 3.10). Among waterways, comparatively low average elevations (e.g., less than 20 percent of the maximum EAR regardless of the normalization) of high molecular weight aromatic hydrocarbons were found only in St. Paul Waterway (Figure 3.10).

Normalized to sediment dry weight, average elevations of all of the chlorinated organic compound groups (i.e., PCBs, chlorinated benzenes, and chlorinated butadienes) were highest in Hylebos Waterway (Figures 3.11, 3.12, and 3.13). Average PCB concentrations (DW) in St. Paul and City Waterways, and along the Ruston-Pt. Defiance Shoreline were also elevated an order of magnitude over reference conditions (Figure 3.11). Dry-weight elevations of chlorinated benzene concentrations did not exceed an order of magnitude, but the average in several areas approached the average observed in Hylebos Waterway (Figure 3.12). Total chlorinated butadienes were elevated greater than an order of magnitude above reference conditions only in Hylebos Waterway sediments, regardless of the concentration normalization used (Figure 3.13).

Average elevations of total phthalate esters (Figure 3.14) did not exceed 10 times reference conditions in any study area. Average concentrations of phthalate esters in the Sitcum, Milwaukee, and St. Paul Waterways were less than reference conditions, regardless of the concentration normalization used.

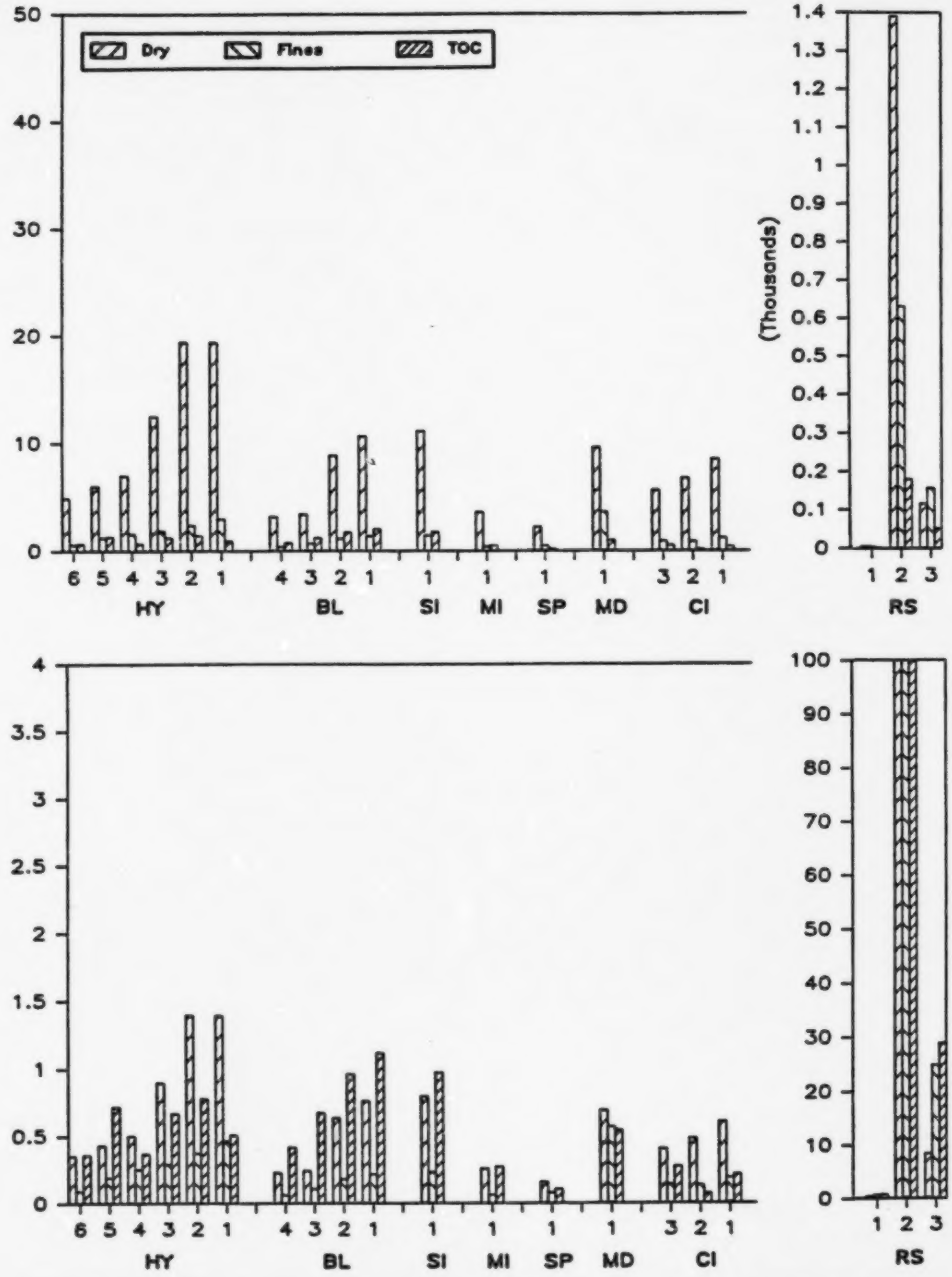
Distributions of the same chemicals and chemical groups shown in Figures 3.7-3.14, but summarized on the basis of the average EARs observed in each of the 20 segments (Table 3.11) are presented in Figures 3.15-3.22. The format of each pair of graphs and the use of three different concentration normalizations are identical to those just described for Figures 3.7-3.14. Data for segments within each area are arranged from the mouth of each waterway (left) to the head (right), and from the eastern end of the Ruston-Pt. Defiance Shoreline (left) to the western end (right).

The high average EARs observed for metals along the Ruston-Pt. Defiance Shoreline were limited to segment RSS2 and, to a lesser extent, RSS3 (Figures 3.15 and 3.16). Average EARs of these metals on a dry-weight basis in the waterways tended to increase from the mouth to the head of larger waterways (e.g., Hylebos, Blair, and City). EARs normalized to percent fine-grained material tended to be more constant along the waterways.



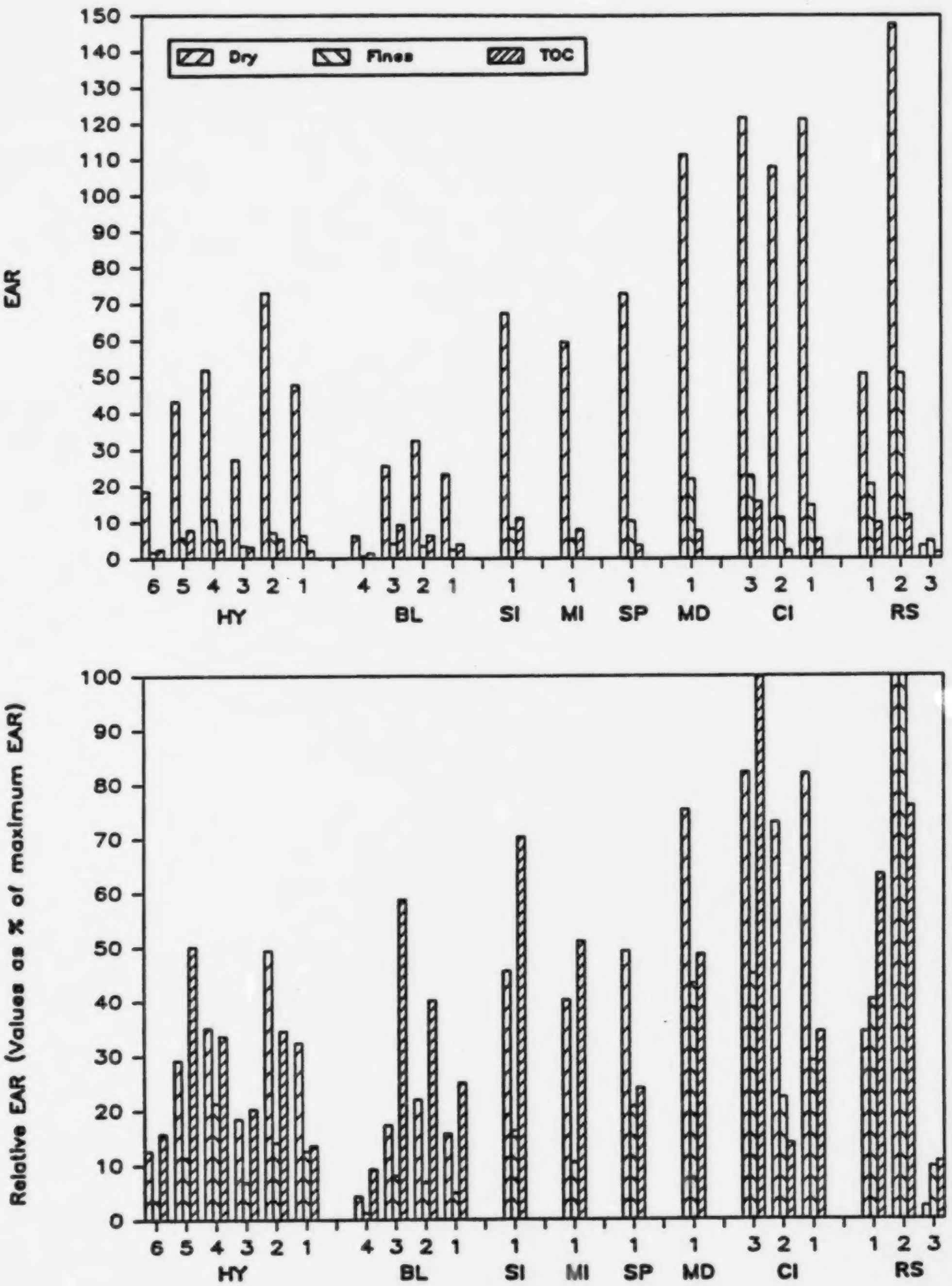
NOTE: Mean reference (µg/kg): 34 (DW); 360 (% fines): 11,000 (TOC)

Figure 3.15. Elevations above reference (EAR) for Pb, Cu, Zn by segment in Commencement Bay study areas.



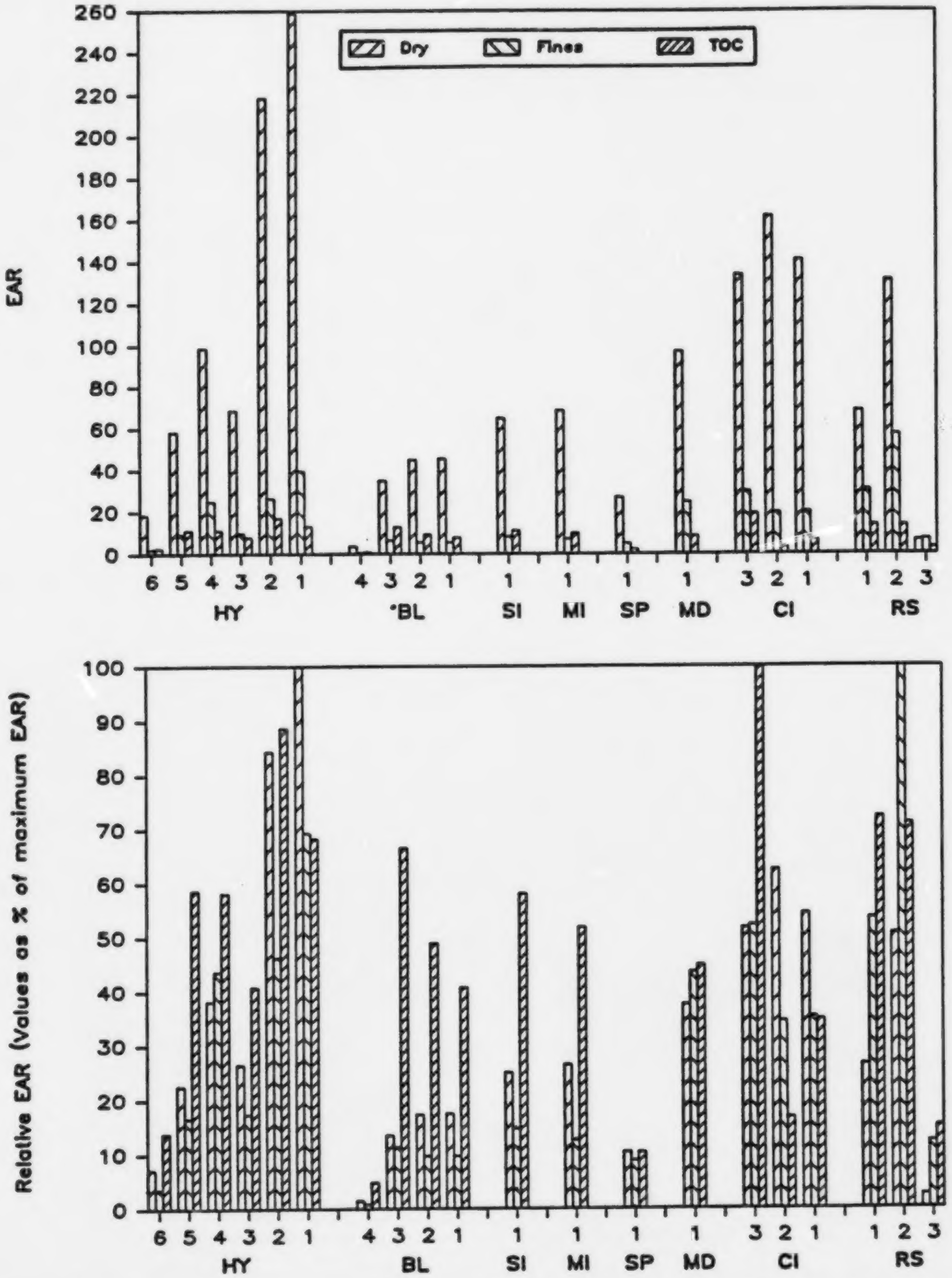
NOTE: Mean reference (µg/kg): 3.4 (DW); 35 (% fines): 1,100 (TOC)

Figure 3.16. Elevations above reference (EAR) for arsenic by segment in Commencement Bay study areas.



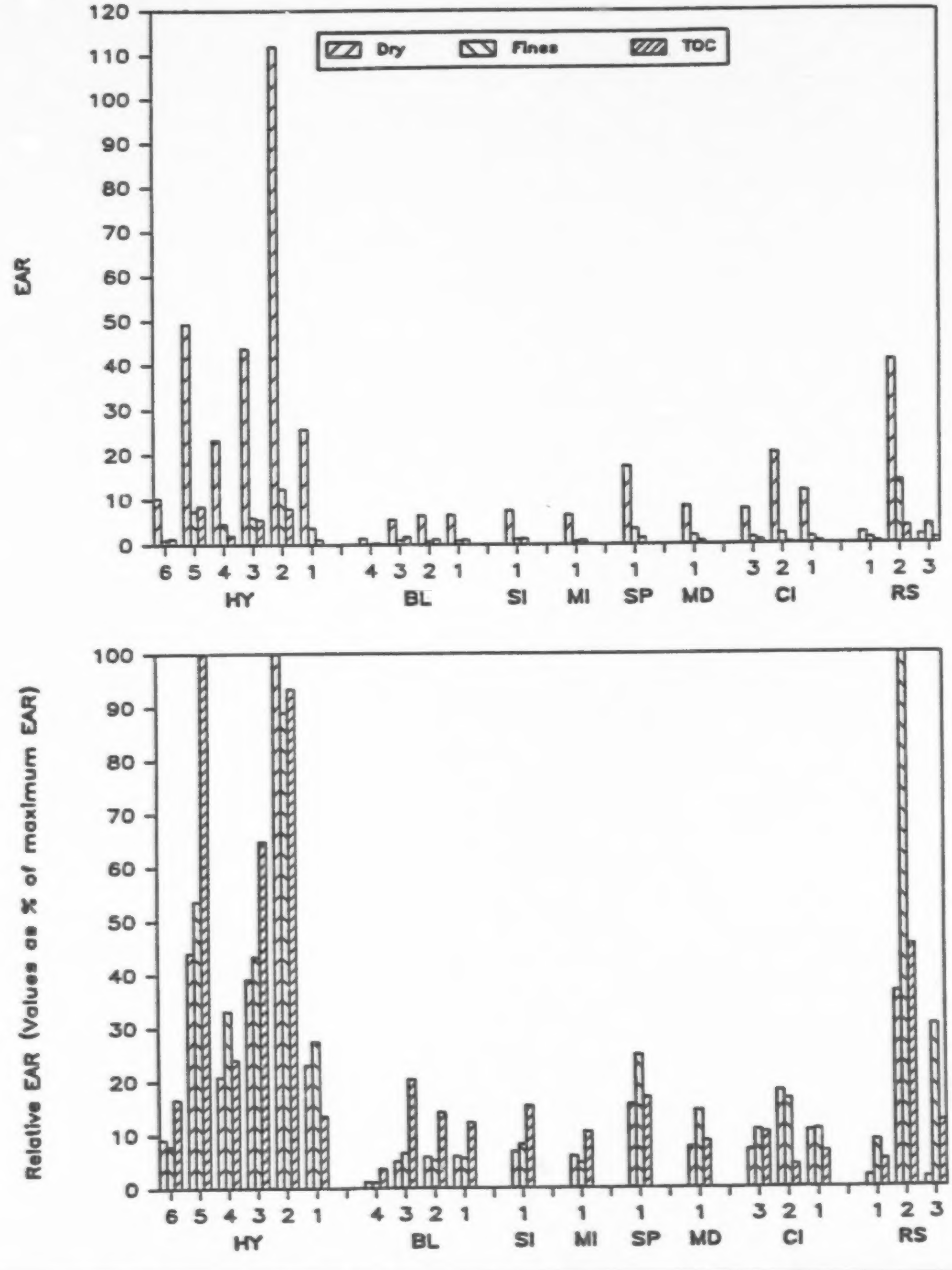
NOTE: Mean reference (µg/kg): 41 (DW); 450 (% fines): 12,000 (TOC)

Figure 3.17. Elevations above reference (EAR) for low molecular weight aromatic hydrocarbons by segment in Commencement Bay study areas.



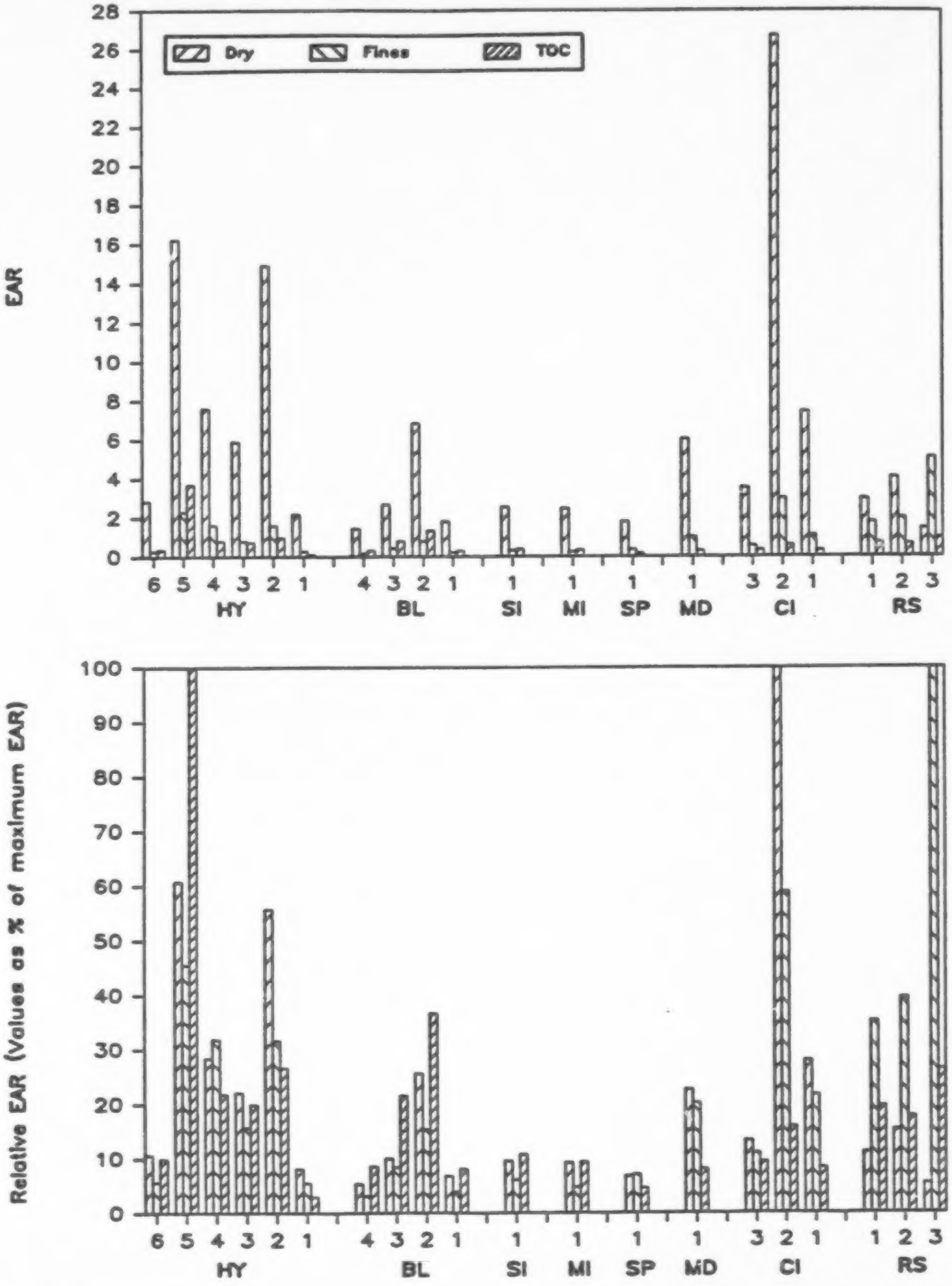
NOTE: Mean reference (µg/kg): 79 (DW); 830 (% fines): 24,000 (TOC)

Figure 3.18. Elevations above reference (EAR) for high molecular weight aromatic hydrocarbons by segment in Commencement Bay study areas.



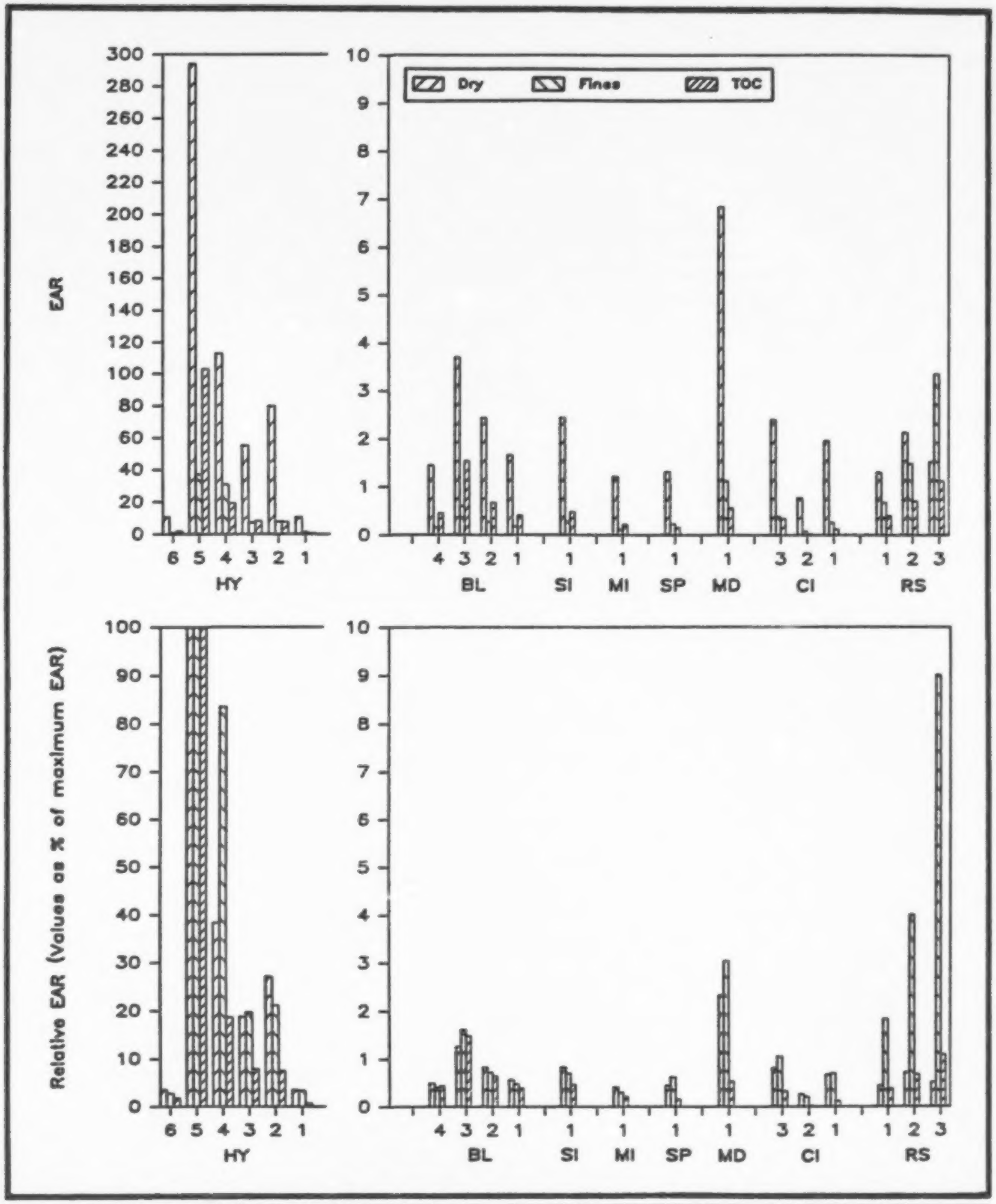
NOTE: Mean reference (µg/kg): 6.0 (DW); 68 (% fines): 2,000 (TOC)

Figure 3.19. Elevations above reference (EAR) for total PCBs by segment in Commencement Bay study areas.



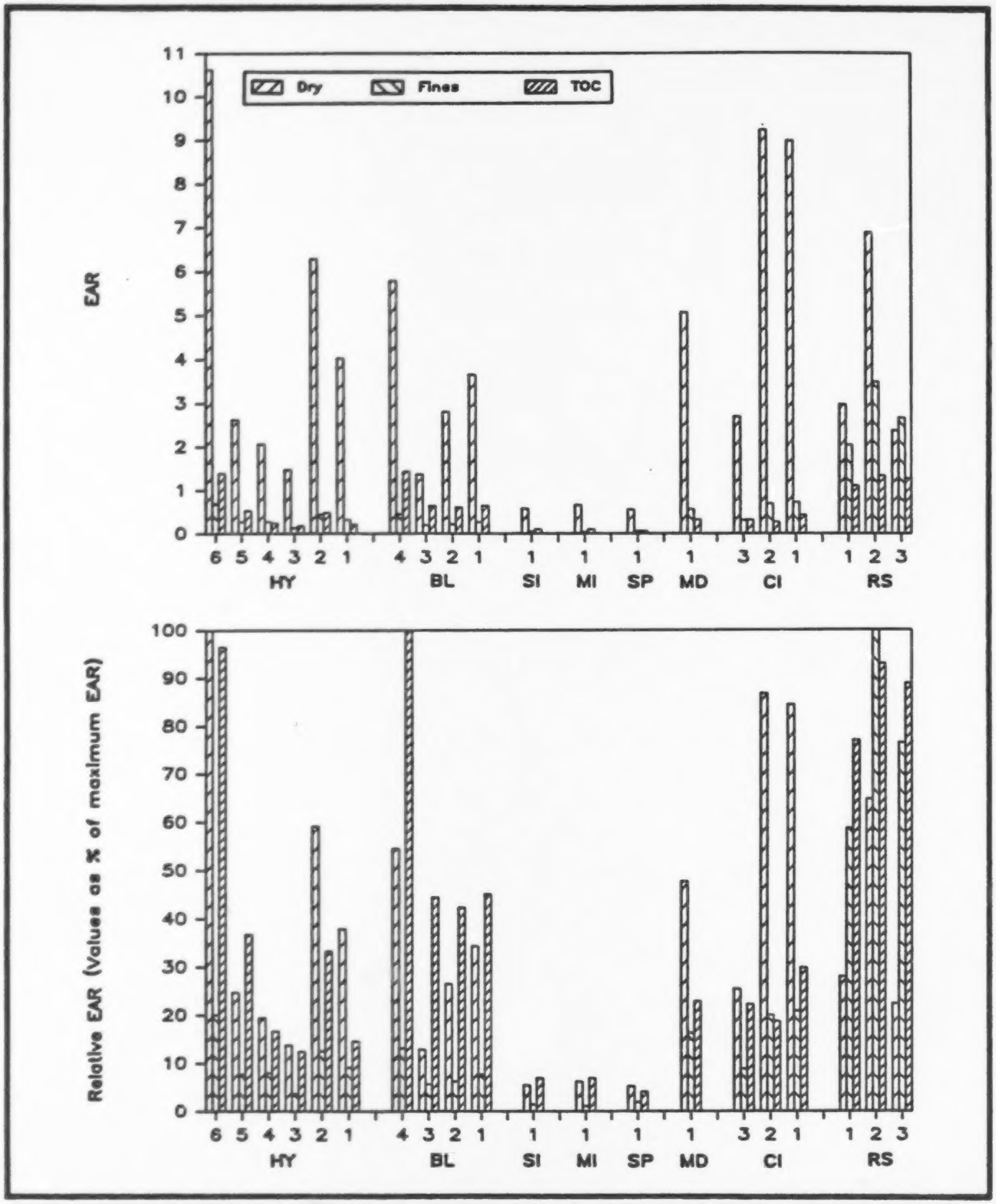
NOTE: Mean reference (µg/kg): 21 (DW); 250 (% fines); 7,400 (TOC)

Figure 3.20. Elevations above reference (EAR) for total chlorinated benzenes by segment in Commencement Bay study areas.



NOTE: Mean reference (µg/kg): 62 (DW); 770 (% fines); 16,000 (TOC)

Figure 3.21. Elevations above reference (EAR) for total chlorinated butadienes by segment in Commencement Bay study areas.



NOTE: Mean reference (µg/kg): 280 (DW); 5,000 (% fines): 88,000 (TOC)

Figure 3.22. Elevations above reference (EAR) for total phthalates by segment in Commencement Bay study areas.

A similar tendency [i.e., higher EARs (DW) away from the mouths of the waterways] was observed for aromatic hydrocarbons (Figures 3.17 and 3.18). An upwaterway gradient was most distinct for high molecular weight aromatic hydrocarbon EARs normalized to dry weight in Hylebos Waterway (Figure 3.18). Although Hylebos Waterway sediments contained the highest observed levels of chlorinated organic compounds, the spatial distributions of PCBs, chlorinated benzenes, and chlorinated butadienes were different from each other within Hylebos Waterway (Figures 3.19-3.21). Highest average PCB concentrations (DW) were found toward the head of Hylebos Waterway, but total chlorinated butadiene and benzene concentrations were substantially more elevated toward the mouth of Hylebos Waterway.

The distribution of phthalates in study area segments is shown in Figure 3.22. High levels (DW) of phthalates were observed in sediment samples from the head of City Waterway and from Wheeler-Osgood Waterway in organic-rich sediments that were contaminated with other chemicals. Unlike any of the other contaminant groups, the highest sediment elevations of phthalates (DW) was found in segment HYS6 outside of Hylebos Waterway. Sediment samples from segment BLS4, outside of Blair Waterway, had the highest phthalate elevations in Blair Waterway. This similarity between the two waterways, and the relatively low contamination levels in the outermost segments by other chemical groups commonly associated with urban contamination, suggests that phthalates have an independent source in this area. A potential contribution from natural sources cannot be ruled out. The low phthalate elevations in Sitcum, Milwuakee, and St. Paul Waterways adjacent to the Puyallup River tend to suggest that discharges from the Puyallup River are not the source.

The relative magnitude of concentrations of other chemicals showing distributions similar to those summarized in Figures 3.17-3.22 are not shown. Chemical characteristics of individual sites will be summarized in detail in later discussions of problem areas (see Section 6).

3.1.6 Comparison with Historical Conditions

Concentrations of most chemicals measured in the current investigation of Commencement Bay subtidal sediments are comparable to or higher than surface sediment values measured in recent studies conducted by WDOE, U.S. EPA, NOAA, and other groups. Available historical concentrations of metals and organic compounds in subtidal and intertidal sediments from Middle and Milwaukee Waterways, and from along the Ruston-Pt. Defiance Shoreline are comparable to or lower than those in the present study. High levels of chlorinated butadienes were observed at a single historical station near Old Tacoma on the Ruston-Pt Defiance Shoreline, but repeated sampling did not confirm the report. Few historical data were found for any sediment contaminants along the Ruston-Pt. Defiance Shoreline or for organic compounds within Middle Waterway. Concentrations of chemicals found during the Commencement Bay Deep Water Sediment Investigation (Hileman and Matta 1983) were lower overall than those found in the waterways during the present investigation. Major differences between historical and current results for metals and organic compounds in the remaining study areas are summarized below. Phthalate ester concentrations are not compared because most historical data were not corrected for potential laboratory contamination.

3.1.6.1 City Waterway--

A single station with high PCB values (300-600 ug/kg DW) was measured during 1980 NOAA studies west of the 11th Street Bridge in City Waterway (Malins et al. 1980). Much lower PCB values were observed in sediments from this area in the present study (e.g., 20-100 ug/kg DW at Stations CI-18, CI-19, and CI-20). A U.S. EPA 1981 study detected hexachlorobutadiene (HCBD) (340 ug/kg dry weight) at the mouth of City Waterway (U.S. EPA 1982); HCBD was undetected at a detection limit of 25 ug/kg DW in the present study.

3.1.6.2 St. Paul Waterway--

Historical metals levels in sediments from St. Paul Waterway were somewhat higher overall than the current findings, but were within a factor of 10. PCBs had been detected in the middle of the waterway at 250 ug/kg DW; the highest value in the current study was 79 ug/kg DW near the mouth of the waterway. PCBs were undetected in sediments from remaining stations at a detection limit of approximately 100 ug/kg DW. A single historical pentachlorophenol value of 840 ug/kg DW was not confirmed in recent samples; pentachlorophenol was undetected throughout the waterway at a detection limit of 25-100 ug/kg DW.

3.1.6.3 Sitcum Waterway--

Copper, lead, and zinc data collected by Tetra Tech indicate an increasing gradient in the concentrations of these metals toward the head of the waterway. Historical data indicate a more patchy distribution with elevated concentrations along the north shore and in the northeast corner (U.S. EPA/DOE 1981 station). There is no consistent trend in concentration of those metals when all data are considered. Concentrations of several aromatic hydrocarbons in a single historical sediment sample collected during a 1981 U.S. EPA/DOE study near Station SI-14 were more than 10 times currently observed concentrations. The unusually high proportion of benzo(a)pyrene relative to other aromatic hydrocarbons in this historical sample was not found in the current samples from Sitcum Waterway.

3.1.6.4 Blair Waterway--

Historical intertidal concentrations of PCBs at the north Lincoln Avenue drain (740 ug/kg DW) were approximately 20 times higher than any present concentrations in Blair Waterway subtidal samples from the same area. Arsenic, chromium, copper, lead, and zinc concentrations at two historical intertidal stations near the south Lincoln Avenue drain exceeded 10 times currently measured subtidal values in the same area. Station BL-14 toward the head of Blair Waterway near the north shoreline had higher concentrations of organic compounds (primarily hydrocarbons) than any historical Blair Waterway sample.

3.1.6.5 Hylebos Waterway--

The most extensive historical data set for sediment contaminants was collected in Hylebos Waterway. At the head of the waterway (segment HYS1), historical contaminant concentrations were comparable to or less than those measured in the current studies, with the exceptions of a single intertidal sample near the Kaiser Ditch with high PCBs (980 ug/kg DW) and intertidal samples with higher aromatic hydrocarbon concentrations,

In the lower turning basin near Stations HY-20 to HY-26 (segment HYS2), historical intertidal sediment concentrations of chloroform, arsenic, copper, and mercury exceeded currently measured subtidal sediment values, but by less than a factor of 10, with the exceptions of chloroform (a factor of 220 over the detection limit of the current studies) and mercury (a factor of 30). All historical intertidal samples were collected from the south shore of the waterway. Historical subtidal sediment concentrations of metals were comparable to those in the current study. The maximum historical concentration of PCBs in surface sediments within this area was 1150 ug/kg DW, approximately half the 2,000 ug/kg DW measured at Station HY-22.

Historical sediment concentrations of metals and organic compounds in segment HYS3 near the Lincoln Avenue drain were in general agreement with those from the current study. Subtidal sediments from Station HY-27 in this segment contained relatively high concentrations of PCBs (860 ug/kg DW). Similarly high concentrations were observed at a nearby historical subtidal station (>1,000 ug/kg DW), but an historical intertidal sample collected near the Lincoln Avenue drain had much lower concentrations (170 ug/kg DW). These data suggest that the drain may not be an ongoing source of PCBs to the subtidal sediments, but that older sediments contaminated with PCBs may have been exposed in the middle of the waterway.

PCB concentrations 10 times higher than those measured in the current study were found in historical samples collected in segment HYS4 near Station HY-32. Aldrin and alpha-HCH were also reported in historical samples, but at concentrations near the detection limits attained in the current study.

Concentrations of lead 35 times greater than those measured in the current study were found in historical intertidal sediments on the south side of Hylebos Waterway near Station HY-42 (segment HYS5). Historical subtidal metal concentrations were comparable to those in the current study. Higher hexachlorobutadiene, hexachlorobenzene, and PCB concentrations (3,300, 1,300, and 1,700 ug/kg DW, respectively) were reported historically in surface sediments (0-2 cm) of this segment than in the current study. However, HCBD and HCB concentrations in the surface interval of cores (e.g., 0-15 cm) collected during the current study in this area were comparable or higher than those in historical surface samples. Aldrin was also detected at 62-950 ug/kg DW in historical intertidal and subtidal sediments collected near HY-42, although the pesticide was undetected in the current study at a detection limit of 50 ug/kg DW. As previously discussed, the historical reporting of aldrin may be a false EC/GC identification of an interfering chlorinated substance. There were no available historical data within segment HYS6, which is outside of Hylebos Waterway.

With the exception of unconfirmed reports of selected pesticides (see discussion in Section 3.1.4.1) in sediments from isolated stations, there were no organic compounds or metals detected in historical Commencement Bay studies that were not also found in the current studies. Besides the differences summarized in this section, the major difference between the available historical studies and the current study is that a wider range of chemicals were quantitated at typically lower detection limits in the current study.

3.1.7 Contamination of Waterway Suspended Solids

The water quality study was designed to provide a qualitative check on the movement of contaminated particulate material among Commencement Bay waterways. A survey of nine stations (two depth intervals) was conducted in April, 1984 during a flood tide and high flow from the Puyallup River. In August, 1984, sampling was conducted at the same locatons at ebb tide and low flow from the Puyallup River. Stations were located in the Puyallup River and Hylebos, Blair, Sitcum, Milwaukee, and City Waterways (see Figure 2.4). Water sampling in the upper portions of Hylebos, Blair, and City Waterways was conducted to characterize the contaminant distribution within these larger waterways.

For both April and August studies, the Puyallup River samples had the highest total suspended solids (TSS) concentrations of all samples collected (6.7 mg/L, 9.8 mg/L). The mouth of City Waterway had the lowest surface TSS load (1.2 mg/L). Little difference was seen between April and August TSS concentrations (except for the Puyallup River samples). Vertical stratification between the surface and 5-m depth, as measured by TSS ratios, also remained fairly constant between April and August.

The April data showed the presence of both HPAH and LPAH (200-8,900 ug/kg DW) and phthalates (380-36,000 ug/kg DW) in all the sampled waterways. Other organic compounds detected included: 4-methylphenol in the Puyallup River (6,100 ug/kg DW), benzoic acid at the head of Blair Waterway (270,000 ug/kg DW) and dibenzofuran at the head of City Waterway (810 ug/kg DW). No other organic compounds were detected above the relatively high analytical detection limits obtained for this survey (500-50,000 ug/kg DW). Concentration gradients of organic contaminants along the waterways were not observed for the April study.

Most metals were detected in the particulate samples. Arsenic was found in highest concentration (290 and 390 mg/kg DW for the subsurface and surface samples, respectively) at the head of Hylebos Waterway. Arsenic concentrations increased from the mouth to the head of Hylebos Waterway. A similar gradient was observed in arsenic sediment concentrations in Hylebos Waterway. However, the August particulate sample data showed no gradient in arsenic concentrations, and the concentrations at the head of Hylebos Waterway were much lower than previously observed (6.2 and 100 mg/kg DW for the subsurface and surface samples, respectively). Concentrations of arsenic in particulate material within Hylebos Waterway appear to be related to existing Hylebos sources that fluctuate with time rather than to a source from outside of the waterway. This conclusion is consistent with the findings of a recent report on the log sort yards in the area (Norton and Johnson 1985a).

Organic compound data from the August sampling effort provided more information because of an approximately fivefold to tenfold increase in analytical sensitivity compared with the April study. HPAH and LPAH were the main organic compounds detected at the mouths of all the waterways sampled (43-6,600 ug/kg DW). Additional compounds detected included: 4-methylphenol at the mouths of Sitcum Waterway, Milwaukee Waterway, and the Puyallup River (2,900-6,600 ug/kg DW); pentachlorophenol at the head of Blair Waterway (440 ug/kg DW); phthalates in all waterway samples except those from Milwaukee Waterway (130-1,600 ug/kg DW); isophorone in Sitcum Waterway (170-610 ug/kg DW); and dibenzofuran in Sitcum, Milwaukee, and City Waterways, and the Puyallup River (65-330 ug/kg DW). No other compounds were reported in any sample above the approximate 250-5,000 ug/kg DW detection limits attained for these particulate samples.

There were no apparent horizontal concentration gradients in Blair or City Waterways for any chemical detected during the the August sampling period. Concentrations of HPAH increased slightly towards the head of Hylebos Waterway (e.g., fluoranthene 610-4600 ug/kg DW). A similar gradient of HPAH concentrations was observed in Hylebos Waterway sediments. As discussed previously for arsenic, the observed distribution of HPAH on Hylebos Waterway particulate material appears to reflect contributions from intermittent local sources within Hylebos Waterway. These data do not suggest that highly contaminated suspended particles are moving out of Hylebos Waterway. In general, the chemical data for suspended solids show little evidence of a major transport of contaminated particles into or out of any of the the waterways sampled.

For both the April and August samples, the concentrations (DW) of organic chemicals bound to suspended solids were more than 10 times higher than the corresponding sediment concentrations. The concentrations of metals bound to suspended solids were similar to those measured in waterway sediment samples. The reasons for this relative difference in concentrations for organic compounds and metals have not been determined. No major qualitative differences in the composition of related substances (e.g., individual PAH compounds) were found between the contaminants on suspended solids and those in the underlying sediments.

3.1.8 Summary

A patchy distribution of contamination was observed in Commencement Bay. Several contaminants were found at concentrations in excess of 1,000 times reference conditions at a few locations. As a means of summarizing this variable distribution, chemicals or chemical groups of concern for which concentrations exceeded 80 percent of the values observed in all Commencement Bay sediments analyzed are listed (by station) in Table 3.15. Where the 80th percentile value did not exceed the range observed for Puget Sound reference areas, a higher percentile was used. The station listing is organized by area and segment to show contiguous stations with high levels of contamination.

The decision-making approach specifies that stations with chemical concentrations exceeding the 80th percentile cutoff described be prioritized for evaluation of potential source control. This chemical prioritization of problem areas will be incorporated with later evaluations of the relationships among sediment contamination, toxicity, and biological effects to determine the final prioritization of problem areas for remedial action.

TABLE 3.15. STATION LOCATIONS AT WHICH SEDIMENT CONCENTRATIONS OF CHEMICALS EXCEEDED 80 PERCENT OF SEDIMENT CONCENTRATIONS MEASURED IN ALL COMMENCEMENT BAY STUDY AREAS

Segment	Station	Chemical[a]																							
HYS1	HY-11		$\boxed{\text{As}}^{c}$							PNOL															
	HY-12 b			Hg		HPAH				$\boxed{\text{PNOL}}$							$\boxed{\text{PHTH}}$			DTP			DIB		
	HY-13		As	Hg		HPAH																			
	HY-14 b					HPAH				PNOL										DTP	$\boxed{\text{MEB}}$				
	HY-15					$\boxed{\text{HPAH}}$													$\boxed{\text{APAH}}$	DTP	MEB		$\boxed{\text{DIB}}$	PCC	$\boxed{\text{COP}}$
	HY-16	CPZ	As		LPAH	$\boxed{\text{HPAH}}$	$\boxed{\text{PCB}}$			$\boxed{\text{PNOL}}$									$\boxed{\text{APAH}}$	$\boxed{\text{DTP}}$	$\boxed{\text{MEB}}$				COP
	HY-17 b	CPZ	$\boxed{\text{As}}$			$\boxed{\text{HPAH}}$	PCB						$\boxed{\text{VOLA}}$						APAH	DTP	$\boxed{\text{MEB}}$		$\boxed{\text{DIB}}$		
	HY-18 b	CPZ	As	Hg		$\boxed{\text{HPAH}}$																			
	HY-19 b	CPZ	As			$\boxed{\text{HPAH}}$	PCB										PHTH				$\boxed{\text{MEB}}$				
HYS2	HY-20		As			$\boxed{\text{HPAH}}$	PCB	CBD		PNOL						$\boxed{\text{BZOH}}$			APAH					PCC	COP
	HY-21		As			$\boxed{\text{HPAH}}$	$\boxed{\text{PCB}}$	CBD								$\boxed{\text{BZOH}}$	$\boxed{\text{PHTH}}$		APAH						
	HY-22 b	CPZ	$\boxed{\text{As}}$	Hg	LPAH	$\boxed{\text{HPAH}}$	$\boxed{\text{PCB}}$	CBD	$\boxed{\text{CBEN}}$	$\boxed{\text{PNOL}}$					$\boxed{\text{DBF}}$		$\boxed{\text{PHTH}}$		$\boxed{\text{APAH}}$		$\boxed{\text{MEB}}$		$\boxed{\text{DIB}}$	PCC	
	HY-23 b		As	Hg	LPAH	HPAH	$\boxed{\text{PCB}}$	CBD					$\boxed{\text{VOLA}}$	BZAC											
	HY-24 b	CPZ	As	Hg		HPAH	PCB	CBD									PHTH								
	HY-25				LPAH		PCB	$\boxed{\text{CBD}}$									PHTH								
	HY-26					$\boxed{\text{HPAH}}$	PCB							BZAC											
HYS3	HY-01	CPZ	$\boxed{\text{As}}$							$\boxed{\text{PNOL}}$															
	HY-27						$\boxed{\text{PCB}}$	CBD								BZOH						RET		PCC	
	HY-28 b							$\boxed{\text{CBD}}$					VOLA								$\boxed{\text{MEB}}$				
	HY-29						PCB	CBD								BZOH				DTP	MEB			PCC	
	HY-30						PCB																		
	HY-31							CBD	CBEN									NDPA			MEB				
HYS4	HY-32 b			Hg				CBD																$\boxed{\text{PCC}}$	
	HY-33					HPAH		$\boxed{\text{CBD}}$								BZOH		NDPA			MEB			$\boxed{\text{PCC}}$	
	HY-34						PCB				MNOL	PCP												$\boxed{\text{PCC}}$	
	HY-35							CBD	CBEN			PCP												$\boxed{\text{PCC}}$	COP
HYS5	HY-36			Hg				CBD	$\boxed{\text{CBEN}}$	$\boxed{\text{PNOL}}$				BZAC	DBF				$\boxed{\text{APAH}}$			$\boxed{\text{RET}}$		PCC	$\boxed{\text{COP}}$
	HY-37 b						$\boxed{\text{PCB}}$	$\boxed{\text{CBD}}$	CBEN	PNOL										DTP			DIB	PCC	
	HY-38						PCB	CBD	CBEN							BZOH								PCC	COP
	HY-39							$\boxed{\text{CBD}}$	$\boxed{\text{CBEN}}$															PCC	
	HY-02																							PCC	
	HY-40			$\boxed{\text{Hg}}$			PCB	$\boxed{\text{CBD}}$	$\boxed{\text{CBEN}}$							$\boxed{\text{BZOH}}$								PCC	COP
	HY-41							$\boxed{\text{CBD}}$	$\boxed{\text{CBEN}}$							$\boxed{\text{BZOH}}$	$\boxed{\text{PHTH}}$							$\boxed{\text{PCC}}$	$\boxed{\text{COP}}$
	HY-42 b						$\boxed{\text{PCB}}$	$\boxed{\text{CBD}}$	$\boxed{\text{CBEN}}$	PNOL										$\boxed{\text{DTP}}$			DIB	$\boxed{\text{PCC}}$	
	HY-43 b							$\boxed{\text{CBD}}$	CBEN	PNOL			VOLA							$\boxed{\text{DTP}}$		RET	DIB	$\boxed{\text{PCC}}$	
	HY-44 b																								
	HY-45							$\boxed{\text{CBD}}$	$\boxed{\text{CBEN}}$															$\boxed{\text{PCC}}$	
	HY-03						$\boxed{\text{PCB}}$	CBD																$\boxed{\text{PCC}}$	$\boxed{\text{COP}}$
	HY-46			Hg			$\boxed{\text{PCB}}$	$\boxed{\text{CBD}}$	$\boxed{\text{CBEN}}$															$\boxed{\text{PCC}}$	COP
	HY-47 b							$\boxed{\text{CBD}}$	$\boxed{\text{CBEN}}$								PHTH			$\boxed{\text{DTP}}$				$\boxed{\text{PCC}}$	
	HY-48							$\boxed{\text{CBD}}$	$\boxed{\text{CBEN}}$							BZOH								PCC	COP
HYS6	HY-49											PCP				$\boxed{\text{BZOH}}$									
	HY-50 b									PNOL						BZOH									
	HY-51															$\boxed{\text{BZOH}}$									
	CB-11																$\boxed{\text{PHTH}}$								
BLS1	BL-11 b		As									PCP													
	B-11																								
	B-02																								

TABLE 3.15. (Continued)

Segment	Station	Chemical a																				
	BL-01							$\boxed{\text{PNOL}}$									DTP					
	BL-12																					
	BL-13b																DTP					
	BL-14				LPAH	HPAH						DBF		PHTH								
	BL-15b																					
	B-12 b													$\boxed{\text{PHTH}}$								
BLS2	BL-16								MNOL		$\boxed{\text{BZAC}}$				NDPA							
	BL-17																					
	BL-18								MNOL	$\boxed{\text{PCP}}$				PHTH								
	BL-19						CBEN															
	B-03 b		As											PHTH								
	BL-20						CBEN															
	BL-21 b						CREN		MNOL				BZOH									
	BL-22						CBEN											$\boxed{\text{MER}}$				
	BL-23							$\boxed{\text{PNOL}}$						PHTH								
	BL-24						CBEN			PCP												
	BL-25 b																					
	BL-26							PNOL			$\boxed{\text{BZAC}}$				NDPA							
	BL-02																					
	B-14																					
	B-15 b																					
	B-07																					
	B-04 b		As	Hg								DBF										
BLS3	BL-03																					
	BL-27																					
	BL-28 b										BZAC											
	BL-29								$\boxed{\text{MNOL}}$	PCP		DBF										
	B-18																					
	B-09 b													PHTH								
	BL-04							$\boxed{\text{PNOL}}$									$\boxed{\text{DTP}}$					$\boxed{\text{COP}}$
	BL-30									$\boxed{\text{PCP}}$												
	BL-31 b							PNOL	MNOL													
	BL-32						CBEN									APAH			RET		MOX	
	B-17																					
	B-10 b							PNOL														
BLS4	CB-12													$\boxed{\text{PHTH}}$								
	CB-13												BZOH									COP
	CB-14												$\boxed{\text{BZOH}}$									COP
SIS1	SI-11 b	$\boxed{\text{CPZ}}$	$\boxed{\text{As}}$									DBF				APAH	$\boxed{\text{DTP}}$	$\boxed{\text{MEB}}$	$\boxed{\text{RET}}$	DIB	$\boxed{\text{MOX}}$	
	SI-12 b	$\boxed{\text{CPZ}}$													$\boxed{\text{NDPA}}$		$\boxed{\text{DTP}}$		$\boxed{\text{RET}}$		$\boxed{\text{MOX}}$	
	SI-13	CPZ																				
	SI-14				LPAH							$\boxed{\text{DBF}}$				$\boxed{\text{APAH}}$			$\boxed{\text{RET}}$	$\boxed{\text{DIB}}$	MOX	$\boxed{\text{COP}}$
	SI-15 b															APAH			$\boxed{\text{RET}}$		MOX	
MIS1	MI-11 b											DBF				APAH	DTP		$\boxed{\text{RET}}$	DIB	MOX	
	MI-12				LPAH							$\boxed{\text{DBF}}$										
	MI-13 b											DBF									MOX	
	MI-01																				MOX	$\boxed{\text{COP}}$
	MI-14											DBF	BZOH									
	MI-15 b																		RET		MOX	

TABLE 3.15. (Continued)

Segment	Station	Chemical[a]																					
SPS1	SP-11 b																	DTP	MEB	RET		$\boxed{\text{MOX}}$	$\boxed{\text{COP}}$
	SP-12 b									MNOL				BZOH				DTP	MEB			$\boxed{\text{MOX}}$	
	SP-13				LPAH					$\boxed{\text{MNOL}}$		BZAC	$\boxed{\text{DBF}}$	$\boxed{\text{BZOH}}$					MEB			$\boxed{\text{MOX}}$	COP
	SP-14 b				LPAH				$\boxed{\text{PNOL}}$	$\boxed{\text{MNOL}}$			DBF					$\boxed{\text{DTP}}$	$\boxed{\text{MEB}}$	$\boxed{\text{RET}}$		$\boxed{\text{MOX}}$	
	SP-15 b									$\boxed{\text{MNOL}}$								DTP	$\boxed{\text{MEB}}$			$\boxed{\text{MOX}}$	COP
	SP-16 b									$\boxed{\text{MNOL}}$				$\boxed{\text{BZOH}}$						$\boxed{\text{RET}}$		$\boxed{\text{MOX}}$	$\boxed{\text{COP}}$
MDS1	MD-11				$\boxed{\text{LPAH}}$	HPAH		CBEN	$\boxed{\text{PNOL}}$	$\boxed{\text{MNOL}}$	$\boxed{\text{PCP}}$		$\boxed{\text{DBF}}$		PHTH						$\boxed{\text{DIB}}$	MOX	
	MD-01																						
	MD-12 b	CPZ			LPAH				PNOL	$\boxed{\text{MNOL}}$			$\boxed{\text{DBF}}$		$\boxed{\text{PHTH}}$		$\boxed{\text{APAH}}$	$\boxed{\text{DTP}}$		RET	$\boxed{\text{DIB}}$	$\boxed{\text{MOX}}$	
	MD-13	$\boxed{\text{CPZ}}$	As	$\boxed{\text{Hg}}$	LPAH					MNOL												MOX	
CIS1	CI-11 b	$\boxed{\text{CPZ}}$		$\boxed{\text{Hg}}$	LPAH	HPAH		$\boxed{\text{CBEN}}$	PNOL	MNOL			$\boxed{\text{DBF}}$	$\boxed{\text{BZOH}}$					MEB		$\boxed{\text{DIB}}$		
	CI-12	$\boxed{\text{CPZ}}$		Hg	$\boxed{\text{LPAH}}$	HPAH				$\boxed{\text{MNOL}}$		BZAC	DBF	$\boxed{\text{BZOH}}$	$\boxed{\text{PHTH}}$		$\boxed{\text{APAH}}$				$\boxed{\text{DIB}}$		$\boxed{\text{COP}}$
	CI-13 b	CPZ		$\boxed{\text{Hg}}$								BZAC			$\boxed{\text{PHTH}}$						DIB	MOX	
	CI-14	CPZ			LPAH					MNOL				BZOH	PHTH							MOX	
	CI-01	$\boxed{\text{CPZ}}$		$\boxed{\text{Hg}}$	LPAH	$\boxed{\text{HPAH}}$										$\boxed{\text{NDPA}}$							
	CI-15	$\boxed{\text{CPZ}}$			$\boxed{\text{LPAH}}$	HPAH		CBEN					$\boxed{\text{DBF}}$	BZOH	$\boxed{\text{PHTH}}$						DIB		
	CI-17 b	CPZ			LPAH				PNOL	MNOL			DBF				APAH	DTP		RET	DIB	MOX	
	CI-18	CPZ		$\boxed{\text{Hg}}$						$\boxed{\text{MNOL}}$						$\boxed{\text{NDPA}}$							
	CI-03			$\boxed{\text{Hg}}$	LPAH												$\boxed{\text{APAH}}$	$\boxed{\text{DTP}}$	MEB	RET			$\boxed{\text{COP}}$
CIS2	CI-02	$\boxed{\text{CPZ}}$		Hg	LPAH	$\boxed{\text{HPAH}}$	PCB	$\boxed{\text{CBEN}}$	$\boxed{\text{PNOL}}$	$\boxed{\text{MNOL}}$			$\boxed{\text{DBF}}$			NDPA			MEB				
	CI-16 b	CPZ			LPAH			$\boxed{\text{CBEN}}$		$\boxed{\text{MNOL}}$			DBF		$\boxed{\text{PHTH}}$	$\boxed{\text{NDPA}}$					DIB		
CIS3	CI-19											BZAC											
	CI-20 b								$\boxed{\text{PNOL}}$								$\boxed{\text{APAH}}$	$\boxed{\text{DTP}}$	MEB	$\boxed{\text{RET}}$	$\boxed{\text{DIB}}$	$\boxed{\text{MOX}}$	
	CI-21				$\boxed{\text{LPAH}}$	$\boxed{\text{HPAH}}$				MNOL			DBF				APAH					$\boxed{\text{MOX}}$	
	CI-22 b				$\boxed{\text{LPAH}}$	HPAH											APAH			RET			
RSS1	RS-11									MNOL							APAH			$\boxed{\text{RET}}$			
	RS-12 b																						
	RS-04																						
	RS-13 b			Hg	LPAH	HPAH				$\boxed{\text{MNOL}}$			$\boxed{\text{DBF}}$				APAH						
	RS-02																						COP
	RS-14 b									MNOL										RET			
	RS-15																						
RSS2	RS-16	CPZ	$\boxed{\text{As}}$	$\boxed{\text{Hg}}$	$\boxed{\text{LPAH}}$		$\boxed{\text{PCB}}$		PNOL	$\boxed{\text{MNOL}}$			$\boxed{\text{DBF}}$		$\boxed{\text{PHTH}}$				$\boxed{\text{MEB}}$	$\boxed{\text{RET}}$	DIB		
	RS-17	$\boxed{\text{CPZ}}$	$\boxed{\text{As}}$	$\boxed{\text{Hg}}$			$\boxed{\text{PCB}}$																
	RS-20 b		$\boxed{\text{As}}$	$\boxed{\text{Hg}}$																			
	RS-03		$\boxed{\text{As}}$	Hg																			
	RS-19 b	$\boxed{\text{CPZ}}$	$\boxed{\text{As}}$	$\boxed{\text{Hg}}$											PHTH								
	RS-18 b	$\boxed{\text{CPZ}}$	$\boxed{\text{As}}$	$\boxed{\text{Hg}}$	$\boxed{\text{LPAH}}$	$\boxed{\text{HPAH}}$		CBEN	PNOL				$\boxed{\text{DBF}}$			$\boxed{\text{NDPA}}$	$\boxed{\text{APAH}}$		MEB	RET	$\boxed{\text{DIB}}$		
	RS-21	$\boxed{\text{CPZ}}$	$\boxed{\text{As}}$	$\boxed{\text{Hg}}$	$\boxed{\text{LPAH}}$	HPAH	$\boxed{\text{PCB}}$						$\boxed{\text{DBF}}$		PHTH		APAH			RET	$\boxed{\text{DIB}}$		
RSS3	RS-24 b	$\boxed{\text{CPZ}}$	$\boxed{\text{As}}$	Hg												NDPA							
	RS-22 b		As																				

TABLE 3.15 (Continued)

[a] Abbreviations used for chemicals are listed below:

PRIORITY POLLUTANTS AND ADDITIONAL HAZARDOUS SUBSTANCE LIST COMPOUNDS (analyzed for at 138 stations except as noted)

CPZ = Copper, lead, zinc
AS = Arsenic
HG = Mercury
LPAH = Low molecular weight aromatic hydrocarbons
HPAH = High molecular weight aromatic hydrocarbons
PCB = Total PCBs
CBD = Total chlorinated butadienes
CBEN = Total chlorinated benzenes
PNOL = Phenol
MNOL = Methylated phenols
PCP = Pentachlorophenol
VOLA = Tetrachloroethene, ethylbenzene, total xylenes (analyzed for at 20 stations only)
BZAC = Benzoic acid (analyzed for at 126 stations only)
DBF = Dibenzofuran (analyzed for at 126 stations only)
BZOH = Benzyl alcohol (analyzed for at 126 stations only)
phth = Total phthalates
NPDA = n-Nitrosodiphenylamine

Tentatively Identified Compounds (analyzed for at 126 stations only)

APAH (alkyl PAH) = 1,1'-biphenyl
2-methylphenanthrene
1-methylphenanthrene
1-methylpyrene
2-methylpyrene

DTP = Isopimaradiene (diterpene)
unidentified diterpene (possibly kaur-16-ene)

MEB = 1-methyl-2-(1-methylethyl)benzene

RET = Retene

DIB = Dibenzothiophene

PCC = Pentachlorocyclopentane isomer

MOX = 2-methoxyphenol

COP = Coprostanol

[b] Stations with synoptic chemistry, sediment toxicity, and biological data.

[c] Station locations where chemical concentrations exceeded 90 percent of values observed in Commencement Bay sediments are boxed.

3.2 BENTHIC MACROINVERTEBRATES

3.2.1 Introduction

Benthic infauna are an integral part of the Puget Sound estuarine ecosystem. They consume organic materials deposited on and in the sediments, bioturbate the sediments, promote nutrient regeneration from the sediments, and are prey of higher trophic level organisms. Benthic organisms are relatively sedentary, and cannot avoid organic materials and chemical contaminants that are deposited on the bottom. Because they are also sensitive to organic enrichment and chemical contamination of the sediments, benthic organisms are an excellent indicator group by which to assess the areal extent and magnitude of environmental stresses (Pearson and Rosenberg 1978; Wolfe et al. 1982).

The purpose of this section is to describe the general characteristics of benthic communities in Commencement Bay waterways, along the Ruston-Pt. Defiance Shoreline, and in the Carr Inlet reference area. An overall characterization of benthic communities in Commencement Bay and Carr Inlet is presented first, followed by qualitative comparisons of benthic communities among and within these nine study areas. A numerical classification analysis is then used to identify the major types of benthic communities and their distributions among the study areas. Animal-sediment relationships are explored with the aid of statistical analyses to identify sediment characteristics that are important determinants of community structure within and among the nine study areas. Statistical analyses are also used to develop indices of benthic degradation that are later used as decision criteria (Section 3.2.7). Finally, biological conditions observed during the present study are compared with those observed in 1950, to determine whether benthic biological conditions have changed since that time.

3.2.2 Characteristics of Benthic Communities in Commencement Bay and Carr Inlet

During this study, 119,095 individuals belonging to 407 species were collected from 56 sampling stations. The best represented major taxonomic groups in the samples were the Polychaeta (marine worms), Bivalvia (clams), Nematoda (round worms), Crustacea (e.g., amphipods and cumaceans), Echinodermata (e.g., sea cucumbers and brittle stars), Oligochaeta (e.g., tubificid worms), and Sipuncula (marine worms). Two species (i.e., the polychaete *Tharyx multifilis* and the bivalve mollusc *Axinopsida serricata*) accounted for 70,084 individuals or 59 percent of benthic organisms collected (Table 3.16). Because of the preponderance of these two species, annelids and bivalve molluscs were the two best represented major benthic groups. Nematodes were the third most abundant major benthic because densities at a few stations were extremely high. The fourth most abundant major group was the crustaceans, represented primarily by the ostracods *Euphilomedes producta* and *E. carcharodonta*, and the tanaid *Leptochelia dubia*. Echinoderms and other major taxonomic groups were present at low abundances in the samples. Ranked mean abundances of benthic taxa at stations in Carr Inlet, and at stations in Commencement Bay are given in Appendix XIII. Counts of infaunal species in each replicate at each station are also listed.

TABLE 3.16. ABUNDANCES AND RANKS OF THE 10 NUMERICALLY DOMINANT BENTHIC TAXA COLLECTED IN COMMENCEMENT BAY

Taxon[a]	Total Abundance	Rank	Proportion of Total Individuals	Cumulative Proportion
Tharyx multifilis (Po)	42,106	1	0.354	0.35
Axinopsida serricata (Pe)	27,978	2	0.235	0.59
Nematoda	9,784	3	0.082	0.67
Macoma carlottensis (Pe)	4,351	4	0.037	0.71
Lumbrineris sp. gr. 1 (Po)	4,018	5	0.034	0.74
Capitella capitata (Po)	2,771	6	0.023	0.76
Euphilomedes producta (Os)	2,289	7	0.019	0.78
Euphilomedes carcharodonta (Os)	1,836	8	0.015	0.80
Leptochelia dubia (Ta)	1,242	9	0.010	0.81
Prionospio steenstrupi (Po)	1,148	10	0.010	0.82

[a] Po = Polychaeta; Pe = Pelecypoda; Os = Ostracoda; Ta = Tanaidacea.

3.2.3 Comparisons Among Study Areas

3.2.3.1 Numbers of Species--

Mean numbers of species (in some cases higher taxa) per grab sample (i.e., per 0.06 m^2) and mean numbers of individuals/m^2 varied considerably among the study areas (Figure 3.23). The highest mean numbers of species were along the Ruston-Pt. Defiance Shoreline and in Carr Inlet, where they averaged over 40 species per grab. Mean numbers of species in Hylebos, Blair, Sitcum, Milwaukee, St. Paul, Middle, and City Waterways were about 35-50 percent lower, suggesting that some degree of stress was occurring throughout the waterways, compared with adjacent habitats.

Tests for differences in numbers of taxa and numbers of individuals among the nine study areas were conducted using the Kruskal-Wallis test [a nonparametric analog of ANOVA (i.e., analysis of variance)]. This nonparametric test was used in lieu of ANOVA because sample variances were highly heterogeneous (i.e., varied by a factor >10) in both data sets. Transformation of the data using the relationship $Y = \log_{10}(x+1)$ failed to reduce the heterogeneity of the variances to an acceptable level. A posteriori multiple range comparisons were conducted using the Mann-Whitney U-test, as recommended by Winer (1971).

Results of the Kruskal-Wallis test and subsequent multiple range comparisons indicated that numbers of taxa were generally depressed within the waterways (Figure 3.23, Tables 3.17, 3.18). Numbers of taxa were significantly higher ($P<0.05$) in Carr Inlet than in City, Hylebos, Milwaukee, Sitcum, and St. Paul Waterways. The multiple range tests also indicated that numbers of taxa at stations along the Ruston-Pt. Defiance Shoreline were higher than at stations in Hylebos Waterway.

3.2.3.2 Total Abundances--

Total abundances (i.e., numbers of individuals/m^2) also varied among the nine Commencement Bay study areas (Figure 3.23). Abundances tended to be higher in Blair, Sitcum, Milwaukee, and City Waterways than elsewhere. A Kruskal-Wallis test detected statistically significant differences ($P<0.05$) in abundances among the study areas. Subsequent a posteriori tests using the Mann-Whitney U-test located statistically significant differences ($P<0.05$) among 11 pairs of study areas. In general, abundances were higher ($P<0.05$) in Middle and Sitcum Waterways, and lower ($P<0.05$) in St. Paul Waterway. Extreme variations in abundances among the stations in City Waterway (discussed below) may account for the absence of statistically significant differences ($P<0.05$) in abundances between City Waterway and other study areas.

3.2.3.3 Numbers of Species and Abundances of Major Taxonomic Groups--

In general, trends in numbers of species and abundances for the major taxonomic groups (i.e., Polychaeta, Mollusca, Crustacea, and Echinodermata) were similar to those shown in Figure 3.23 for total numbers of species and total abundances. High numbers of polychaete, mollusc, and crustacean species (Figures 3.24, 3.25, 3.26) generally accounted for the high degree of species richness found along the Ruston-Pt. Defiance Shoreline and in Carr Inlet. Polychaetes were very abundant in the Hylebos, Blair, Sitcum,

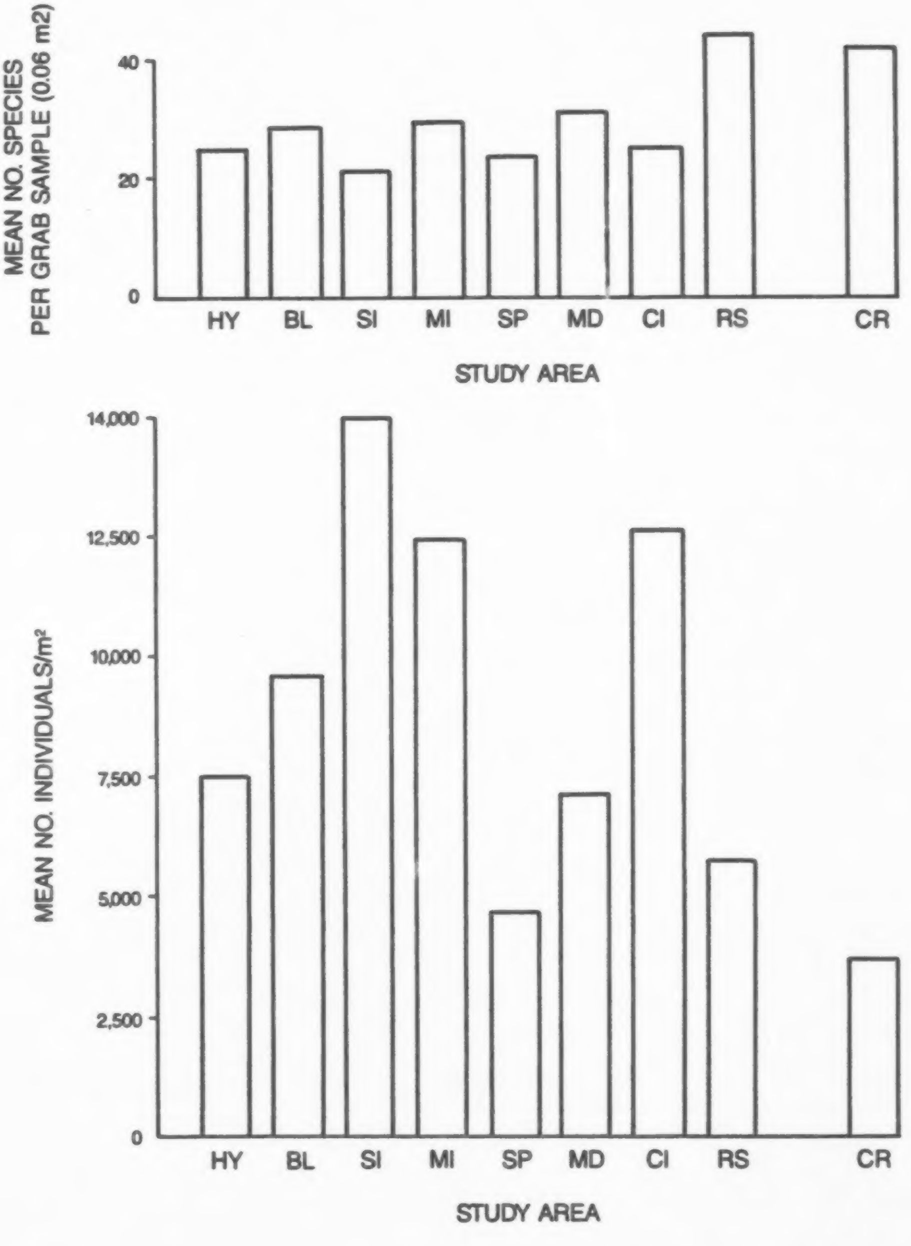


Figure 3.23. Mean number of species per grab sample and mean number of individuals/m^2 in each study area.

TABLE 3.17. RESULTS OF KRUSKAL-WALLIS TESTS COMPARING NUMBERS OF TAXA PER GRAB SAMPLE AND NUMBERS OF INDIVIDUALS PER GRAB SAMPLE AMONG THE STUDY AREAS[a]

Test	No. Cases	Chi-square[b]	Significance[b]
No. Taxa/Grab Sample	192	44.00	0.0000
No. Individuals/Grab Sample	192	38.48	0.0000

[a] Each study area was characterized by the values of all replicates collected therein.

[b] Probability that rank sums are approximately the same; corrected for ties.

TABLE 3.18. RESULTS OF MANN-WHITNEY U-TEST MULTIPLE COMPARISONS OF NUMBERS OF TAXA PER GRAB SAMPLE AND NUMBERS OF INDIVIDUALS PER GRAB SAMPLE AMONG THE STUDY AREAS[a]

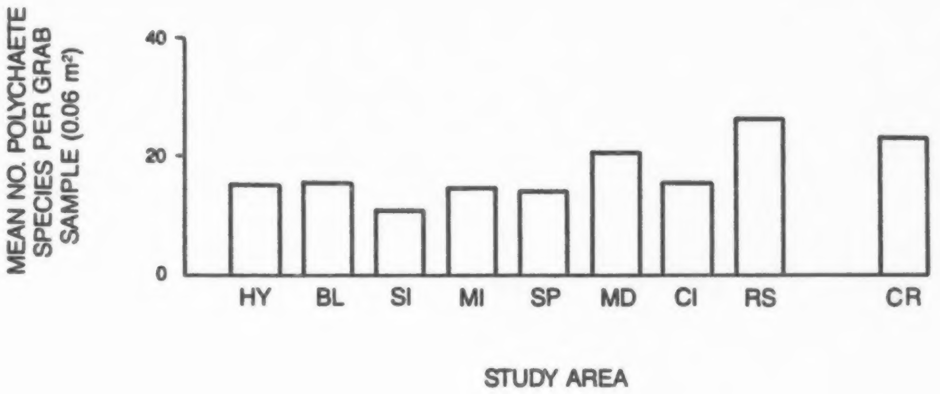
	No. Taxa/Grab Sample							
	CI	CR	HY	MD	MI	RS	SI	SP
BL	ns[b]	ns	ns	ns	ns	ns	ns	ns
CI		*[c]	ns	ns	ns	ns	ns	ns
CR			*	ns	*	ns	*	*
HY				ns	ns	*	ns	ns
MD					ns	ns	ns	ns
MI						ns	ns	ns
RS							ns	ns
SI								ns

	No. Individuals/Grab Sample							
	CI	CR	HY	MD	MI	RS	SI	SP
BL	ns	*	ns	ns	ns	ns	ns	*
CI		ns	ns	ns	ns	ns	ns	ns
CR			ns	ns	*	ns	*	ns
HY				ns	*	ns	*	*
MD					ns	ns	ns	ns
MI						*	ns	*
RS							*	ns
SI								*

[a] Each study area was characterized by the values of all replicates collected therein.

[b] ns = not significant.

[c] Each test was considered significant (*) if $P<0.00625$. This significance level is based on an experimentwise error rate of $P<0.05$ and eight pairwise comparisons for each study area with all other study areas.



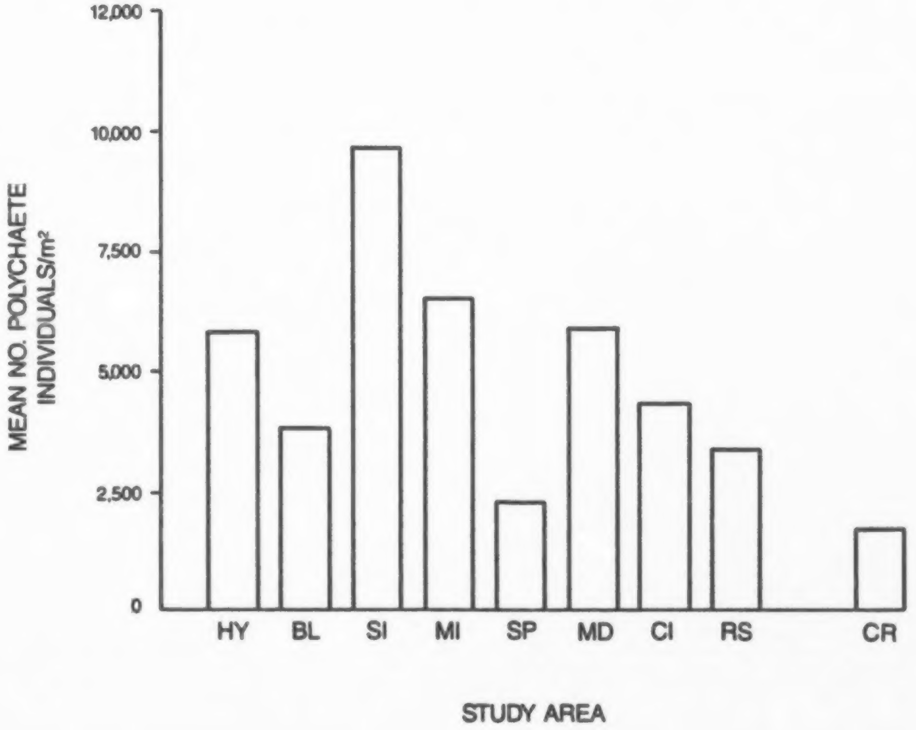


Figure 3.24. Mean number of polychaete species per grab sample and mean number of polychaete individuals/m^2 in each survey area.

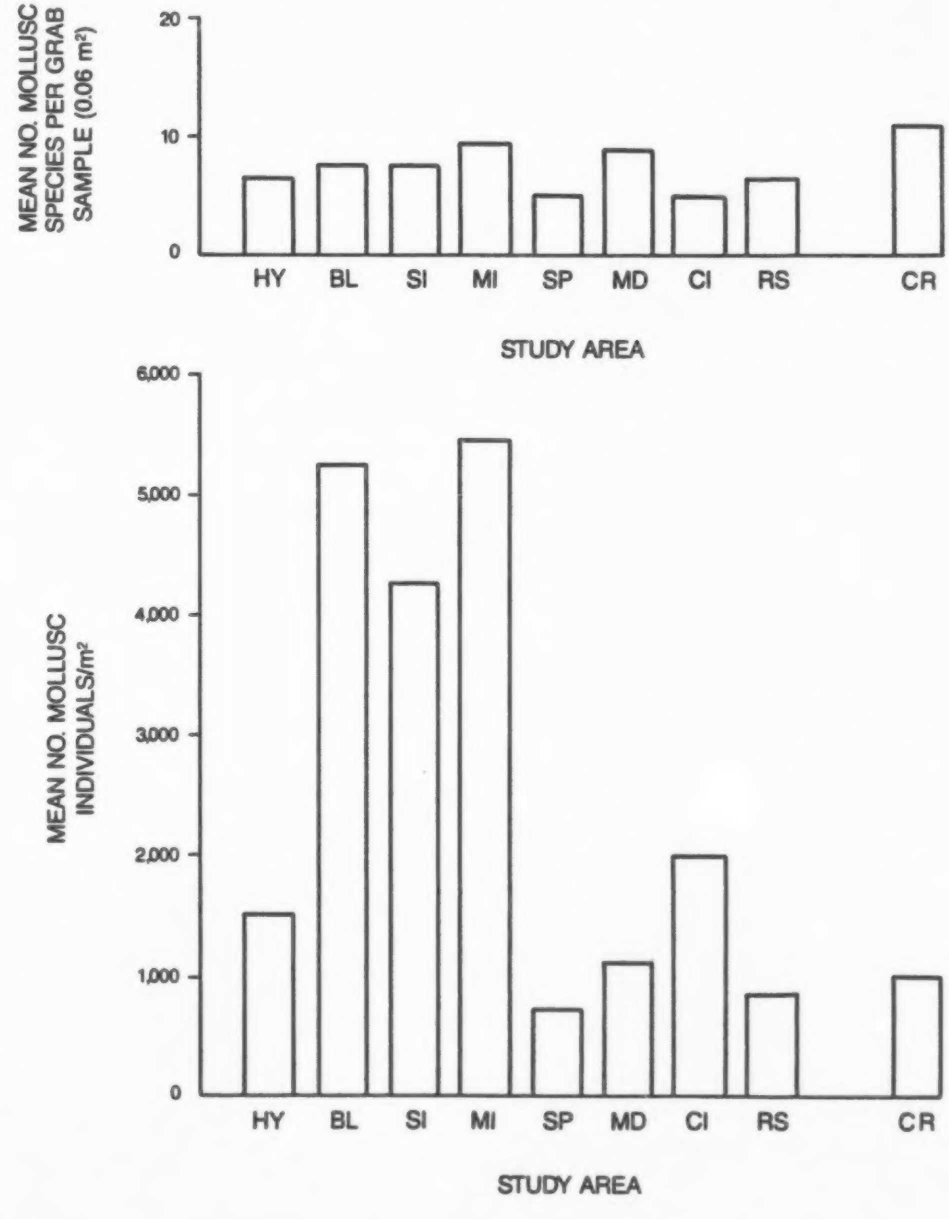


Figure 3.25. Mean number of mollusc species per grab sample and mean number of mollusc individuals/m^2 in each survey area.

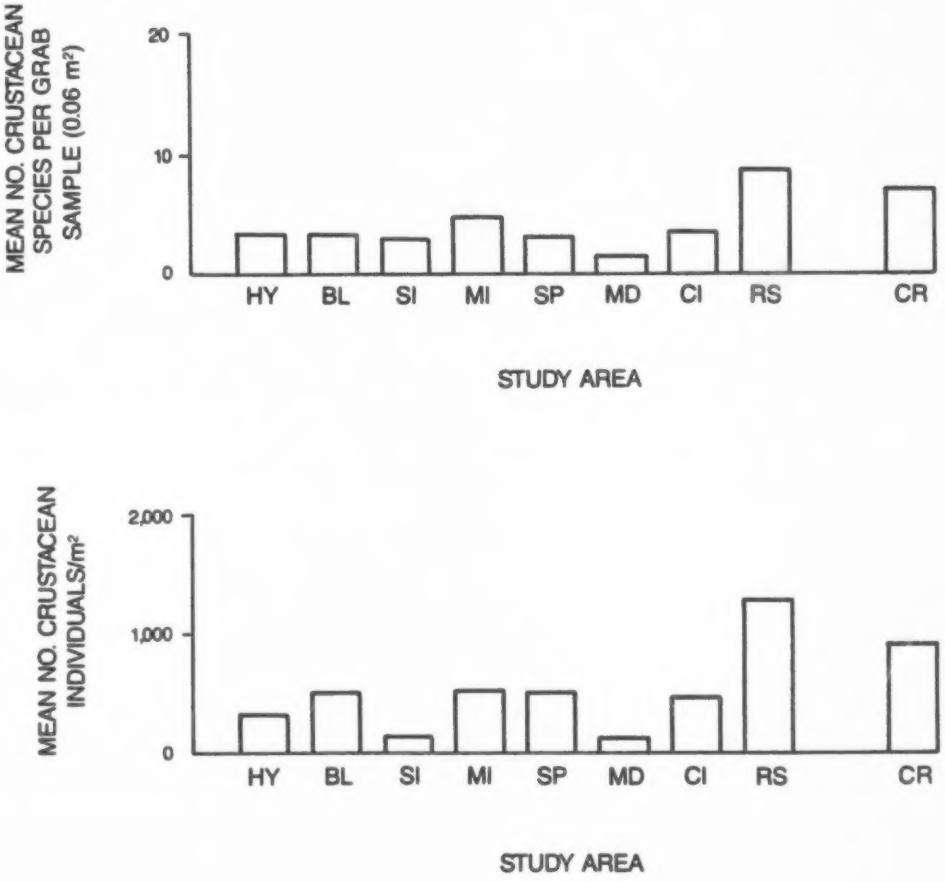


Figure 3.26. Mean number of crustacean species per grab sample and mean number of crustacean individuals/m^2 in each survey area.

Milwaukee, Middle, and City Waterways, while molluscs were very abundant in the Blair, Sitcum, and Milwaukee Waterways. Polychaetesand molluscs accounted for generally enhanced total numerical abundances in the waterways. Echinoderms exhibited low numbers of species and low abundances in all study areas (Figure 3.27).

3.2.3.4 Numerically Abundant Taxa--

Abundances of the five most abundant taxa (i.e., the numerically dominant taxa) in each study area are summarized in Figure 3.28 and Table 3.19. (The data in Figure 3.28 and Table 3.19 are combined for all stations within a study area and are intended to give an overview of conditions within each study area. Taxonomic composition and abundances differed among the stations within many of the study areas, and will be discussed below.) Very high dominance (i.e., 63-95 percent) was exhibited by benthic communities in all study areas except the Ruston-Pt. Defiance Shoreline (i.e., 36 percent) and Carr Inlet (i.e., 44 percent). High dominance values may indicate stressed conditions, since less tolerant species are eliminated and opportunistic species tend to achieve high abundances (Pearson and Rosenberg 1978; Gray 1982).

Taxonomic composition and, hence, the feeding modes of the dominant species differed considerably among the study areas (Figure 3.28, Table 3.19). For all stations combined, the Hylebos, Blair, Sitcum, Milwaukee, and, to a lesser degree, Middle Waterways were dominated by the surface deposit-feeding polychaete Tharyx multifilis and the surface detritus-feeding bivalve mollusc Axinopsida serricata (see Fauchald and Jumars 1979; Word 1980). These two species have not been identified in the scientific literature as being opportunistic. The St. Paul and City Waterways (for all stations combined) were dominated primarily by subsurface deposit-feeding nematodes. The subsurface deposit-feeding polychaete Capitella capitata was the second most abundant taxon in the St. Paul Waterway and the fourth most abundant taxon in Middle Waterway (after nematodes, T. multifilis, and A. serricata). (Note that nematodes and Capitella capitata are not the most abundant taxa throughout either the St. Paul or City Waterways, but are extremely abundant only at certain stations. This will be discussed below.) Both nematodes and the polychaete C. capitata are known to reach very high abundances in organically enriched sediments, often to the near exclusion of other taxa (Nichols 1972; Pearson and Rosenberg 1978; Van Es et al. 1980). The dominance of these two taxa suggests that some sediments in St. Paul and City Waterways are organically enriched.

3.2.3.5 Contaminant-Sensitive Taxa--

Many echinoderm and crustacean species are sensitive to contaminants and environmental disturbance (Reish and Barnard 1979; Word 1978, 1980). Although numbers of echinoderm species and abundances of echinoderms were too low in all of the study areas for useful inter-area comparisons (Figure 3.27), abundances of amphipods (i.e., sensitive crustaceans) may be compared among study areas. Data in Table 3.20 indicate that amphipods were abundant only in Carr Inlet and along the Ruston-Pt. Defiance Shoreline, excluding Station RS-18. A one-way ANOVA was conducted to test for differences in mean amphipod abundances among all Commencement Bay study areas and Carr Inlet using the data in Table 3.20. Middle Waterway was deleted from the analysis

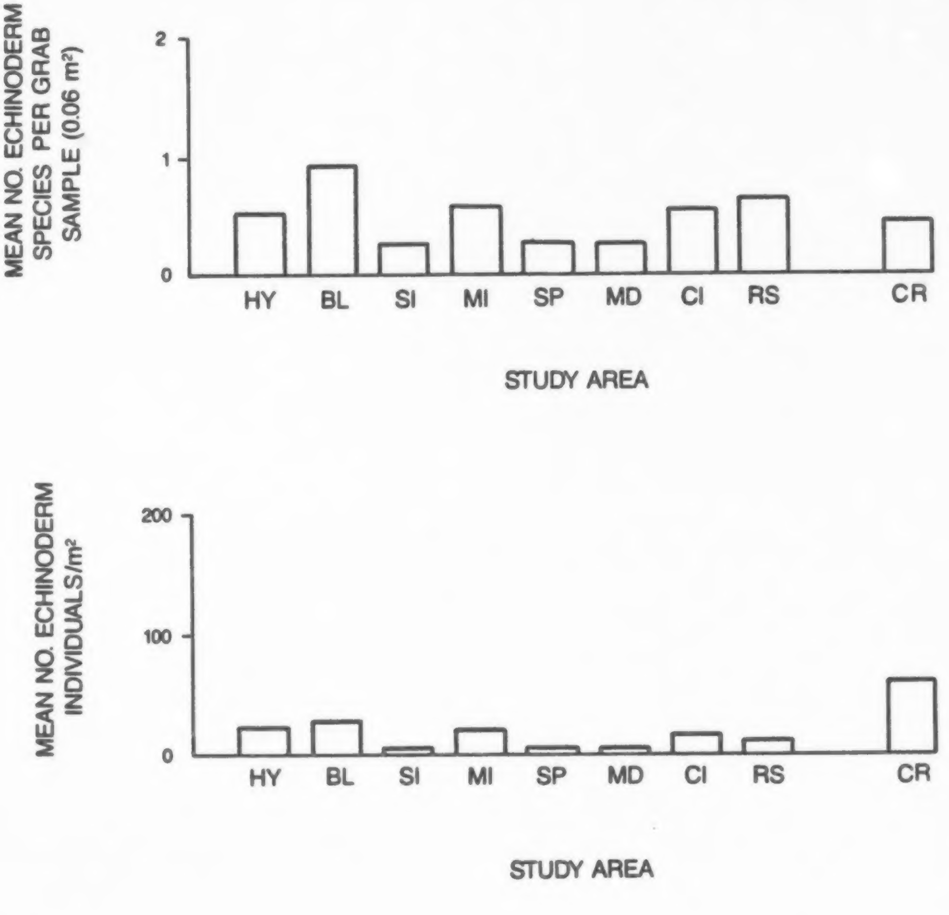
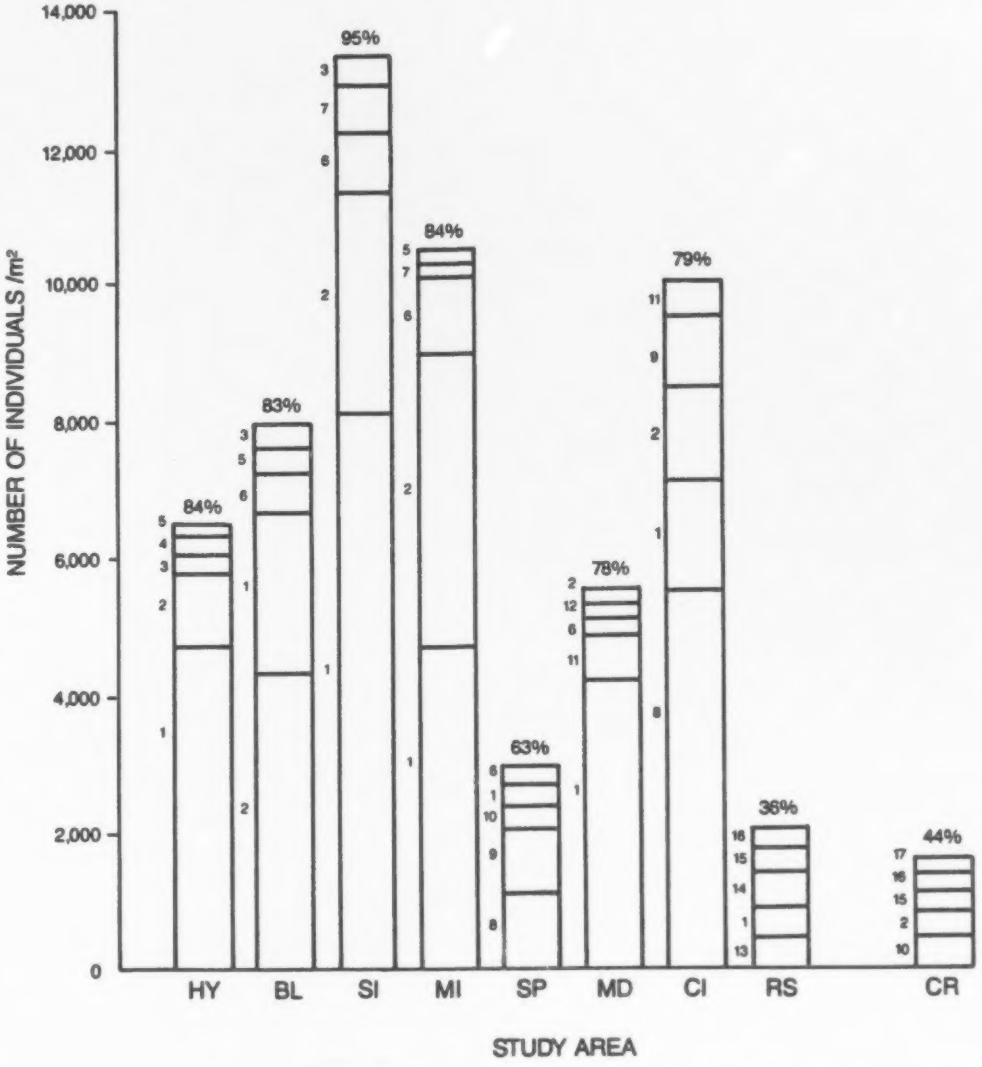


Figure 3.27. Mean number of echinoderm species per grab sample and mean number of echinoderm individuals/m^2 in each study area.



NUMBERS BESIDE THE BARS REFER TO SPECIES LISTED IN TABLE 3.19.

Figure 3.28. Mean abundances per station of the five numerically dominant species per study area and the proportions of total infaunal abundances for which they account.

TABLE 3.19. KEY FOR FIGURE 3.28

1 = *Tharyx multifilis* (Polychaeta)
2 = *Axinopsida serricata* (Pelecypoda)
3 = *Lumbrineris* sp. gr. 1 (Polychaeta)
4 = *Cirratulus cirratus* (Polychaeta)
5 = *Euphilomedes producta* (Ostracoda)
6 = *Macoma carlottensis* (Pelecypoda)
7 = *Lumbrineris luti* (Polychaeta)
8 = Nematoda
9 = *Capitella capitata* (Polychaeta)
10 = *Leptochelia dubia* (Isopoda)
11 = *Cossura soyeri* (Polychaeta)
12 = *Nephtys cornuta franciscana* (Polychaeta)
13 = *Mediomastus* spp. (Polychaeta)
14 = *Euphilomedes carcharodonta* (Ostracoda)
15 = *Prionospio steenstrupi* (Polychaeta)
16 = *Phyllochaetopterus prolifica* (Polychaeta)
17 = *Scalibregma inflatum* (Polychaeta)

TABLE 3.20. NUMBERS OF AMPHIPODS COLLECTED AT EACH OF THE COMMENCEMENT BAY STATIONS (0.24-m^2) SAMPLED IN MARCH, 1984

Station	Abundance	Station	Abundance
HY-12	0	SP-11	25
HY-14	0	SP-12	17
HY-17	1	SP-14	1
HY-22	6	SP-15	1
HY-23	0	SP-16	4
HY-24	3		
HY-28	10	MD-12	0
HY-32	2		
HY-37	2	CI-11	2
HY-42	1	CI-13	1
HY-43	5	CI-16	0
HY-44	6	CI-17	1
HY-47	1	CI-20	0
HY-50	6	CI-22	0
BL-11	1	RS-12	16
BL-13	3	RS-13	200
BL-21	0	RS-14	72
BL-25	1	RS-18	0
BL-28	8	RS-19	29
BL-31	1	RS-20	45
SI-11	1	CR-11	65
SI-12	2	CR-12	14
SI-15	4	CR-13	39
		CR-14	167
MI-11	2		
MI-13	1		
MI-15	3		

because there was only one data point for number of amphipods; a minimum of two points is necessary to estimate the mean and standard deviation. The test found mean abundances to be significantly different ($P<0.05$) among the study areas. A subsequent Student-Newman-Keuls multiple comparison test yielded two nonsignificant subsets of stations, based on a statistical significance level of $P<0.05$. Subset one consisted of the Hylebos, Blair, Sitcum, Milwaukee, St. Paul, and City Waterways, while subset two consisted of the Ruston-Pt. Defiance Shoreline and Carr Inlet. These results further substantiate the hypothesis that amphipod abundances are depressed in the waterways relative to the Ruston-Pt. Defiance Shoreline and Carr Inlet.

Because many amphipod species are sensitive to contaminants, organic enrichment, and environmental disturbance (Bellan-Santini 1980; Swartz et al. 1982b; Oakden et al. 1984), it is probable that one or more of these factors contributed to the depressed amphipod abundances observed in the waterways. Alternatively, the naturally occurring sandy sediments found along the Ruston-Pt. Defiance Shoreline and in Carr Inlet might be expected to support larger amphipod populations than the muddy sediments found in the Commencement Bay waterways. A correlation analysis of amphipod abundances at stations within the waterways (Ruston-Pt. Defiance Shoreline and Carr Inlet excluded) with percent sand in the sediments was conducted during this review. Results were highly significant ($P<0.0001$). Thus, the lower amphipod abundance observed in the Commencement Bay waterways may be due to one or more of types of environmental stress, or to differences in sediment characteristics.

3.2.4 Comparisons Within Study Areas

Considerable variation in numerical abundances and species composition occurred within each study area (Figures 3.29-3.32, Table 3.21). For example, benthic communities along the Hylebos Waterway were dominated by *Tharyx multifilis* and *Axinopsida serricata*, but abundances of those two species combined varied from 137 to 14,546/m^2 among the stations (Figure 3.29). Abundances of the five numerically dominant species exceeded 4,000/m^2 at most stations, but were depressed below this value in the vicinity of Stations HY-22, HY-23, HY-32, HY-37, and HY-44. Greatly depressed abundances often indicate excessively enriched sediments or the presence of contaminants (Pearson and Rosenberg 1978; Carriker et al. 1982; Wolfe et al. 1982; Dillon 1984). The *Tharyx-Axinopsida* community also occurred throughout Blair, Sitcum, and Milwaukee Waterways. Abundances of the five numerically dominant taxa were less variable within each of these waterways than were those observed in Hylebos Waterway (Figure 3.30), and all but Station BL-28 (near the East 11th Street Bridge) exhibited abundances of 8,000/m^2 or greater.

The benthic community at the single station in Middle Waterway also was dominated by *Tharyx multifilis*, with *Axinopsida serricata* present as the fifth most abundant taxon (Figure 3.31). Total abundance of the five most abundant taxa was somewhat lower at the station in Middle Waterway than was typical of those in Blair, Sitcum, and Milwaukee Waterways (5,588/m^2).

Stations in St. Paul Waterway supported very different benthic communities than those observed in the waterways north of the Puyallup River (Figure 3.31). At none of the St. Paul Waterway stations was a *Tharyx-Axinopsida* community found. Nematodes and the polychaete *Capitella capitata* were the most abundant

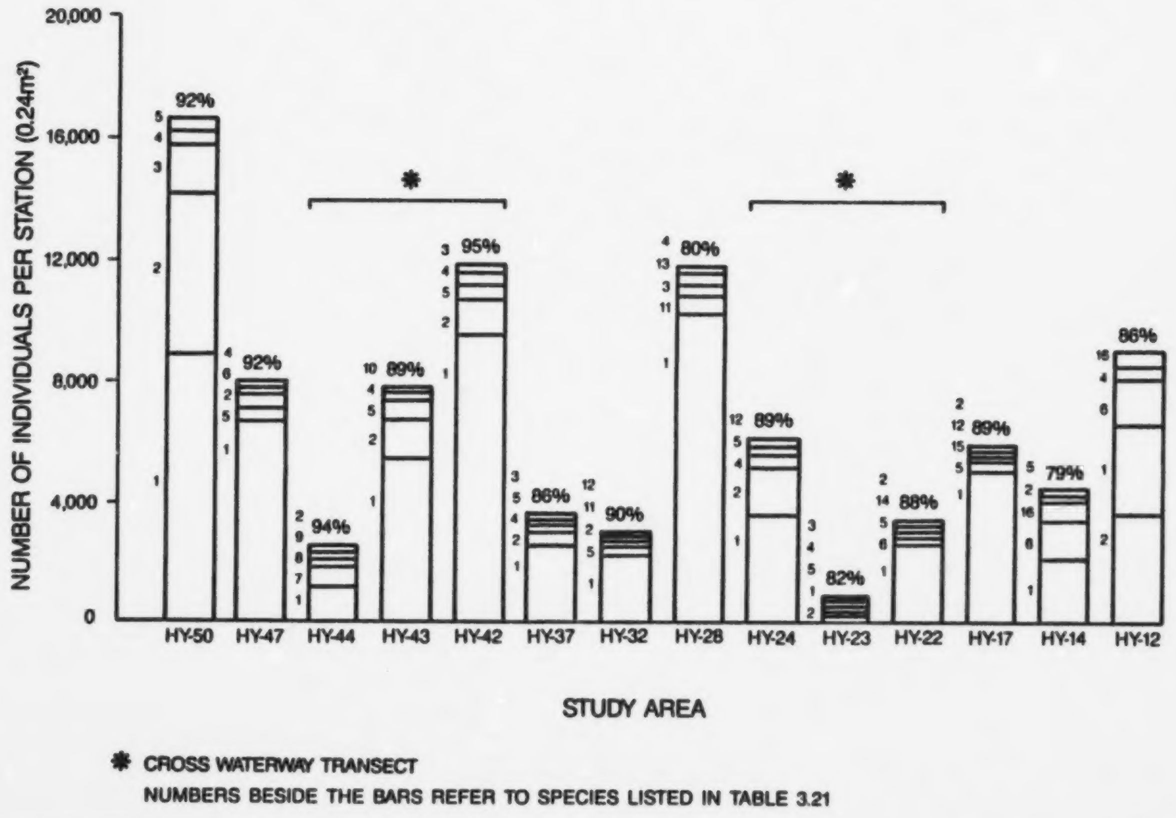
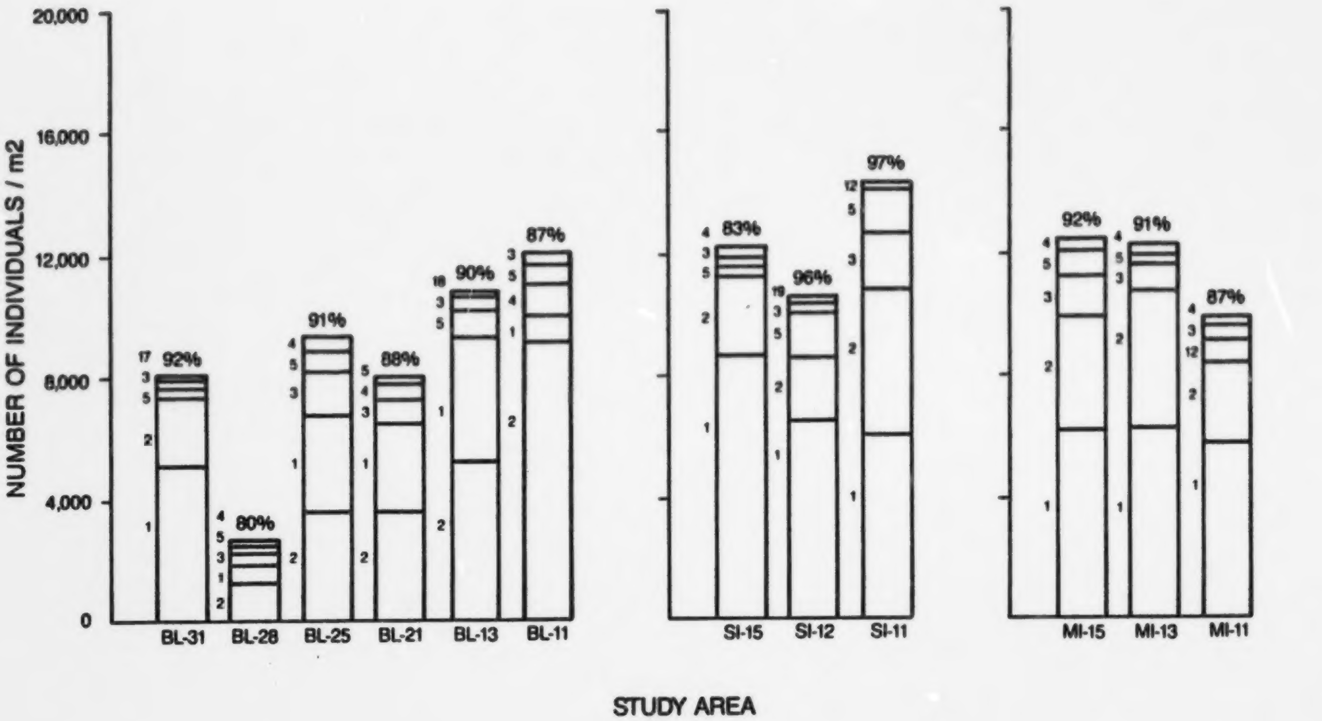


Figure 3.29. Total abundances of numerically dominant species at stations in Hylebos Waterway, and the proportions of total infaunal abundances for which they account.



NUMBERS BESIDE THE BARS REFER TO SPECIES LISTED IN TABLE 3.21.

Figure 3.30. Total abundances of numerically dominant species at stations in Blair, Sitcum, and Milwaukee Waterways, and the proportions of total infaunal abundances for which they account.

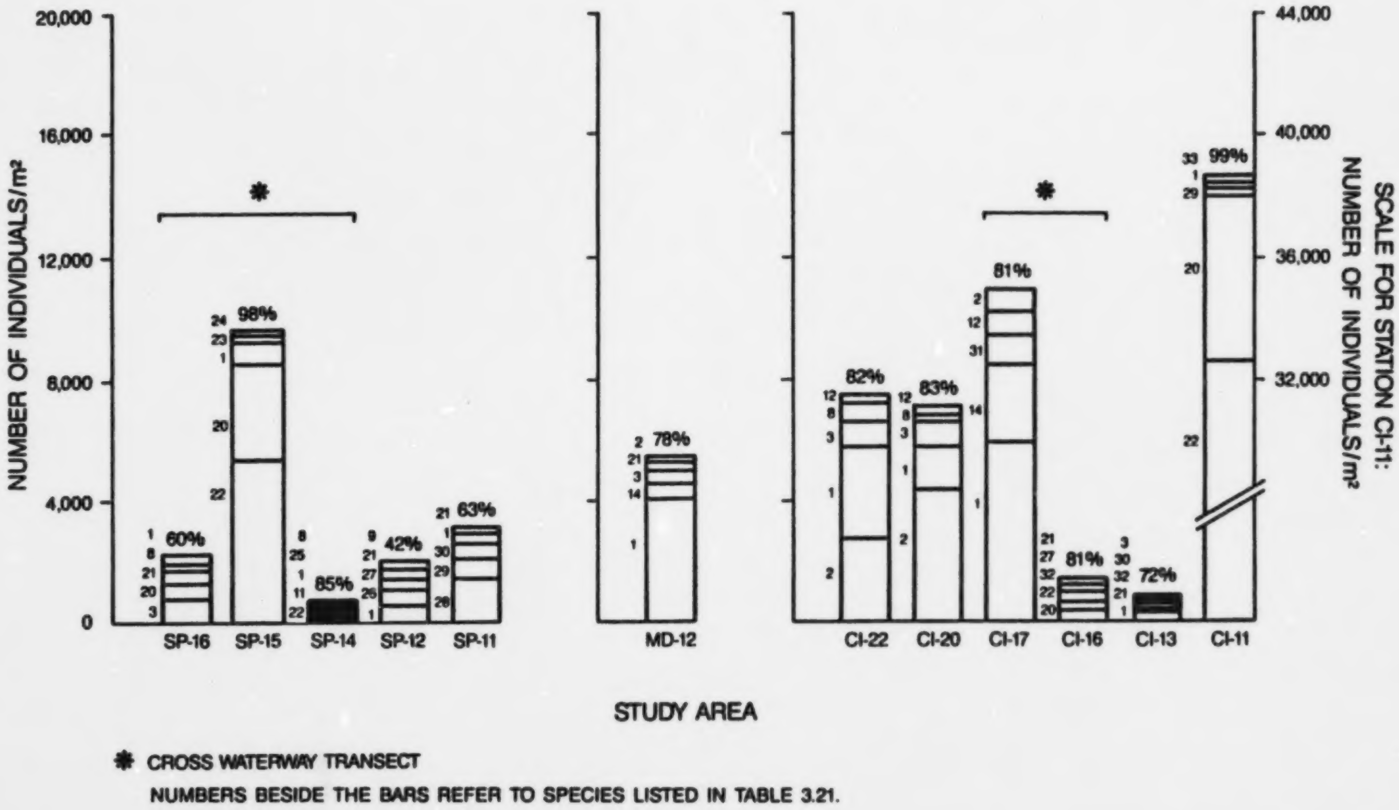


Figure 3.31. Total abundances of numerically dominant species at stations in St. Paul, Middle, and City Waterways, and the proportions of total infaunal abundances for which they account.

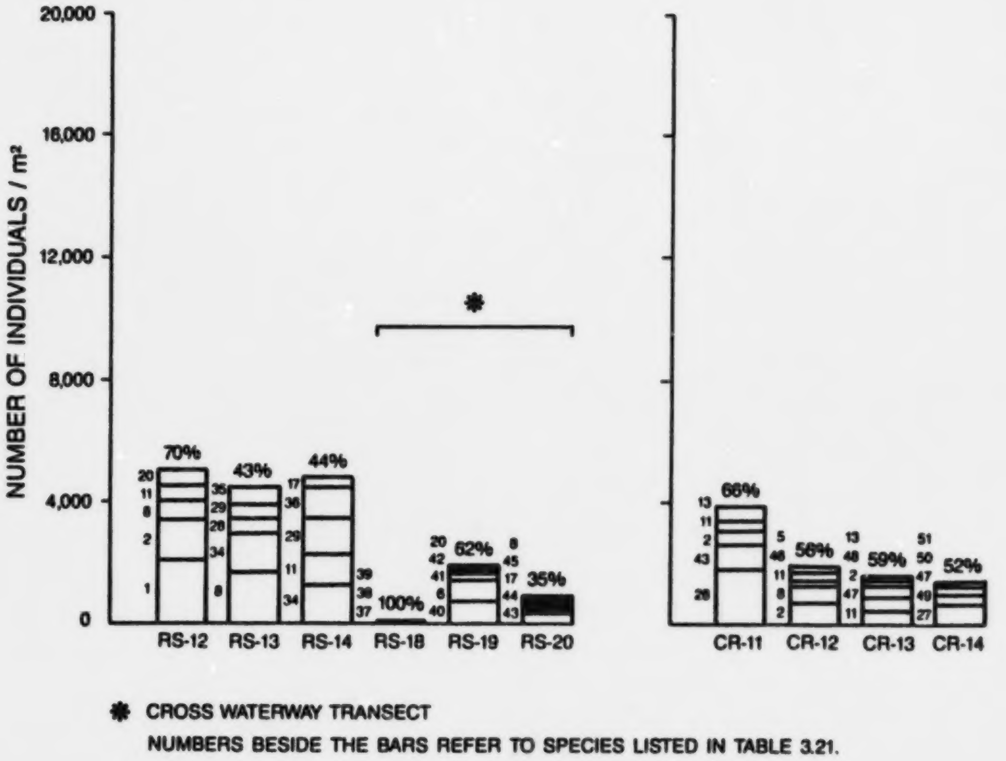


Figure 3.32. Total abundances of the numerically dominant species at stations along the Ruston-Pt. Defiance shoreline and in Carr Inlet and the proportions of total infaunal abundances for which they account.

TABLE 3.21. KEY FOR FIGURES 3.29 THROUGH 3.32

1 = *Tharyx multifilis* (Polychaeta)
2 = *Axinopsida serricata* (Polychaeta)
3 = *Macoma carlottensis* (Pelecypoda)
4 = *Euphilomedes producta* (Ostracoda)
5 = *Lumbrineris* sp. gr. 1 (Polychaeta)
6 = *Cirratulus cirratus* (Polychaeta)
7 = *Psephidia lordi* (Pelecypoda)
8 = *Euphilomedes carcharodonta* (Ostracoda)
9 = *Macoma obliqua* (Pelecypoda)
10 = *Lumbrineris* sp. gr. 3 (Polychaeta)
11 = *Prionospio steenstrupi* (Polychaeta)
12 = *Chaetozone* spp. (Polychaeta)
13 = *Odostomia* spp. (Gastropoda)
14 = *Cossura* spp. (Polychaeta)
15 = *Euchone* sp. A (Polychaeta)
16 = *Pista cristata* (Polychaeta)
17 = *Notomastus tenuis* (Polychaeta)
18 = *Praxillella gracilis* (Polychaeta)
19 = *Glycera capitata* (Polychaeta)
20 = *Capitella capitata* (Polychaeta)
21 = *Nephtys cornuta franciscana* (Polychaeta)
22 = *Nematoda*
23 = Schistomeringos *rudolphi* (Polychaeta)
24 = *Gyptis brevipalpa* (Polychaeta)
25 = *Cancer* sp. (Decapoda)
26 = *Nephtys cornuta* (Polychaeta)
27 = *Macoma nasuta* (Pelecypoda)
28 = *Leptochelia dubia* (Tanaidacea)
29 = *Platynereis bicaniculata* (Polychaeta)
30 = *Macoma nasuta* (Pelecypoda)
31 = *Prionospio cirrifera* (Polychaeta)
32 = *Armandia brevis* (Polychaeta)
33 = Tubificidae (Oligochaeta)
34 = *Mediomastus* spp. (Polychaeta)
35 = *Photis brevipes* (Amphipoda)
36 = *Prionospio multibranchiata* (Polychaeta)
37 = *Leptostylis villosa* (Cumacea)
38 = *Limnoria lignorum* (Isopoda)
39 = *Amphipholis squamata* (Ophiuroidea)
40 = *Balanus crenatus* (Cirripedia)
41 = *Paleonotus bellis* (Polychaeta)
42 = *Pseudochitinopoma occidentalis* (Polychaeta)
43 = *Phyllochaetopterus prolifica* (Polychaeta)
44 = *Polydora* spp. (Polychaeta)
45 = *Pholoides aspera* (Polychaeta)
46 = *Amphiodia urtica* (Ophiuroidea)
47 = *Scalibregma inflatum* (Polychaeta)
48 = *Mitrella gouldi* (Pelecypoda)
49 = *Caprellidae* (Amphipoda)
50 = *Caprella mendax* (Amphipoda)

taxa at Station SP-15 in the outer portion of the waterway. These two taxa contributed most of the organisms collected at that station and were present at a combined abundance of more than 8,000/m^2. As discussed above, the numerical dominance of nematodes and *C. capitata* may indicate highly enriched sediments. The remaining four stations were dominated by an assortment of polychaete, mollusc, and crustacean species, all of which occurred at low combined abundances (<4,000/m^2). Abundances of the five numerically dominant species at Station SP-14, inshore of Station SP-15, were especially depressed (92/m^2), suggesting that a high level of stress was occurring at that station. The very different suites of species among the St. Paul Waterway stations suggest that sediment conditions were highly localized and varied over short distances.

Benthic communities along the length of City Waterway changed markedly in species composition and abundances. Station CI-11, at the head of the waterway, was a nematode-*Capitella capitata* community in which the abundances of nematodes alone exceeded 32,000/m^2. At Stations CI-13 and CI-16, towards the mouth of the waterway, abundances of the numerically dominant taxa become very reduced (<4,000/m^2). *Tharyx multifilis* was the most abundant taxon at Station C-13, while *C. capitata* and nematodes were the two most abundant taxa at Station C-16. Stations CI-17, CI-20, and CI-22 in the outer half of the City Waterway were dominated by *T. multifilis* and *Axinopsida serricata*. Combined numerical abundances of the dominant taxa were about 8,000/m^2 or greater, as was typical of *Tharyx*-*Axinopsida* communities in Blair, Sitcum, and Milwaukee Waterways. Changes in species compositions and abundances within City Waterway suggest that the greatest environmental stresses occurred near the head of the waterway, and that conditions improved toward the mouth of the waterway.

Along the Ruston-Pt. Defiance Shoreline, the *Tharyx*-*Axinopsida* community typical of the waterways was found only at Station RS-12, located near City Waterway. Species composition varied at the remaining stations along the shoreline. The most striking aspect of the data in Figure 3.32 is the reduced abundances of benthic organisms at Stations RS-19 and RS-20, and the nearly abiotic sediments collected at Station RS-18. Of the four replicate benthic grab samples collected at Station RS-18, only two contained any macroinvertebrates (i.e., a total of seven organisms). The virtual absence of benthic biota in the vicinity of Station RS-18 is indicative of severe stress.

3.2.5 Classification Analyses

3.2.5.1 Introduction--

Numerical classification analyses group entities (in this case stations) based on their attributes (in this case abundances of the 64 most abundant taxa collected in the study). They are effective because they reduce complex data sets to groups of entities with similar, and therefore interpretable, characteristics.

The classification analysis conducted during this study involved two steps. The first was to generate similarity values for all possible pairs of stations included in the analysis. The Bray-Curtis Similarity Index (see Boesch 1977) was employed for this purpose. It uses both species composition and abundances of the individual species to estimate between-site similarity. The group average clustering strategy was then applied to the matrix of similarity values to generate a dendrogram of stations (Figure 3.33). Groups of stations (i.e., stations that are most similar in species composition and abundance) may then be determined based on selected similarity levels.

Ideally, a single similarity value should be selected (albeit somewhat subjectively) and all station groups should be determined relative to that value. However, a single similarity level does not yield interpretable station groups when the dendogram exhibits excessive "chaining", or sequential additions of stations or station pairs to the most similar group of stations, as in Figure 3.33. Therefore, several similarity levels have been selected in the following interpretation of the data in Figure 3.33.

Although 56 stations were sampled during this survey, only data from 54 stations were used in the classification analysis and statistical analyses conducted during this study. Steep bottom topography and very sandy sediments were encountered at the remaining two stations off Pt. Defiance, so that it was impossible to collect representative 0.06-m^2 (0.6-ft^2) grab samples. Therefore, those two stations were deleted from further consideration.

3.2.5.2 Results--

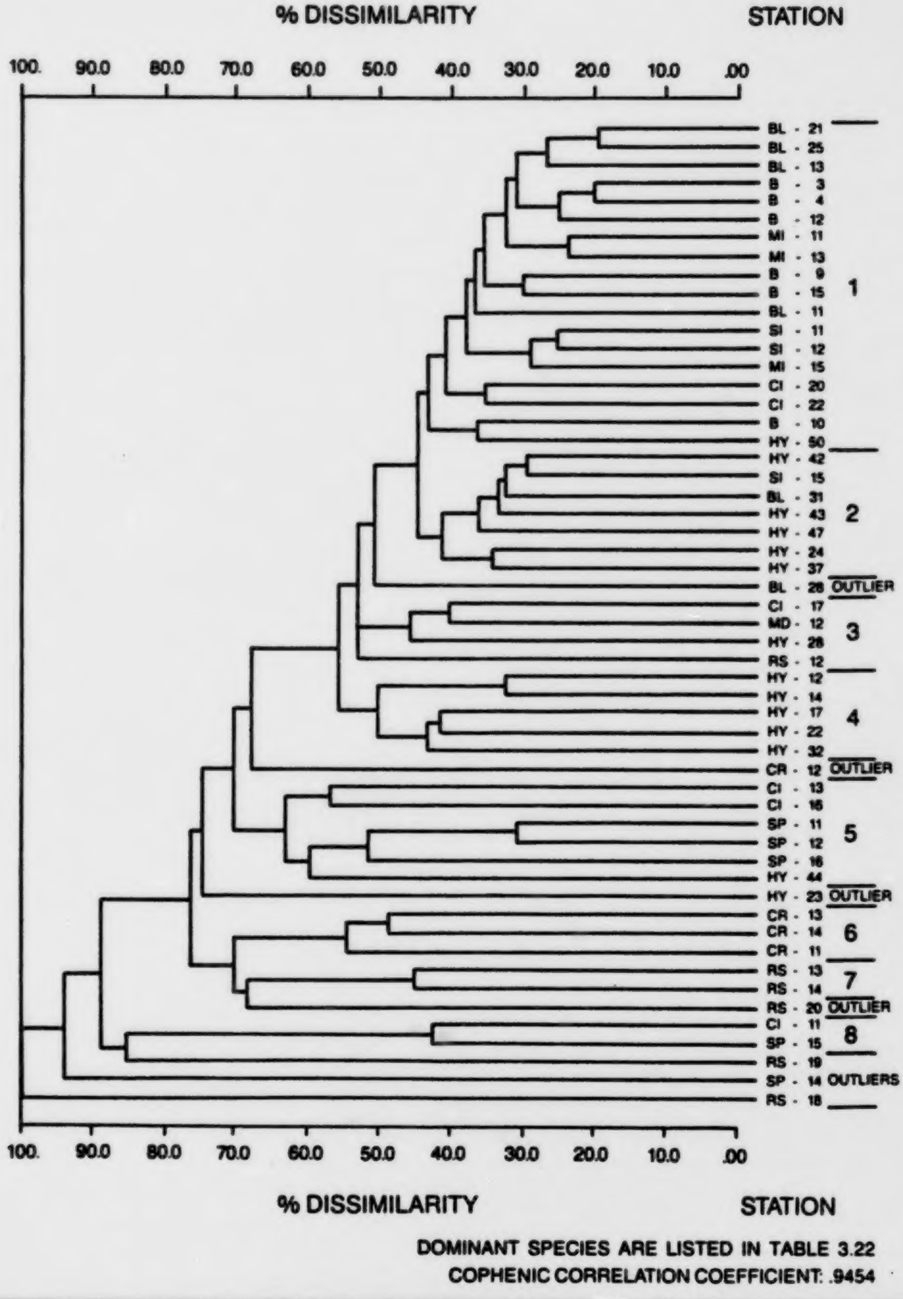
Results of a normal (Q-mode) classification analysis using abundances of the 64 numerically dominant species in the Commencement Bay study areas are shown in Figures 3.33 and 3.34. The dominant species within these station groups, their mean abundances, and mean total volatile solids (TVS) and total organic carbon (TOC) concentrations for the stations in each station group are given in Table 3.22. Sediment grain size characteristics of the major station groups are summarized in Figure 3.35.

3.2.5.3 Interpretation--

Included in Group 1 were the Blair Waterway stations (except BL-28 near the outer bridge and BL-31 near the mouth of the waterway), the Milwaukee Waterway stations, the two inner stations in the Sitcum Waterway, and Station HY-50 off the mouth of the Hylebos Waterway. The two co-dominant species, *Axinopsida serricata* and *Tharyx multifilis*, accounted for most of the individuals collected. Sediments within Group 1 were primarily sandy silts, with moderate organic levels ($\bar{x}$=5.0 percent TVS, $\bar{x}$=1.8 percent TOC).

Group 2 was also dominated by *Tharyx multifilis* and *Axinopsida serricata*, but abundances of *A. serricata* were about five times lower than those of *T. multifilis*. Group 2 included four stations in the outer third of the Hylebos Waterway, Station BL-31 near the mouth of Blair Waterway, and Station HY-24 in upper Hylebos Waterway. The stations in Group 2 had slightly greater quantities of clay than the stations in Group 1, but the major difference was the increased quantities of organic materials ($\bar{x}$=6.3 percent TVS, $\bar{x}$=2.6 percent TOC) compared with Group 1 ($\bar{x}$=5.0 percent TVS, $\bar{x}$=1.8 percent TOC).

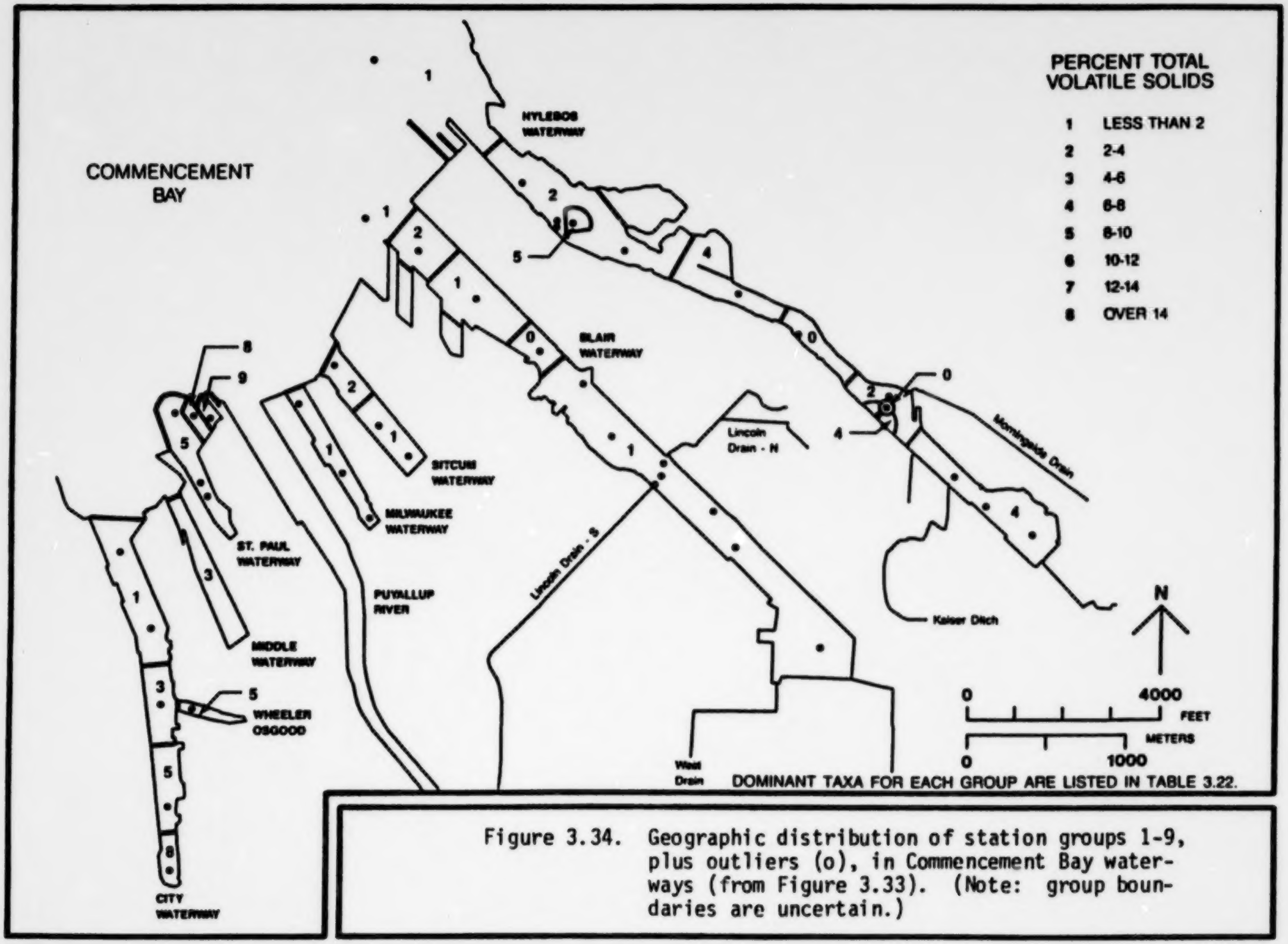
Station BL-28 near the 11th Street Bridge was an outlier to Groups 1 and 2. It was also co-dominated by *Axinopsida serricata* and *Tharyx multifilis*, but at relatively low abundances. The proximity of Station BL-28



DOMINANT SPECIES ARE LISTED IN TABLE 3.22

COPHENIC CORRELATION COEFFICIENT: .9454

Figure 3.33. Results of a Q-mode classification analysis (Bray-Curtis similarity index, group average clustering strategy) using square-root transformed abundances of the 64 numerically dominant infaunal species.


COMMENCEMENT BAY
HYLEBOS WATERWAY
BLAIR WATERWAY
SITCUM WATERWAY
MILWAUKEE WATERWAY
ST. PAUL WATERWAY
MIDDLE WATERWAY
WHEELER OSGOOD
CITY WATERWAY
PUYALLUP RIVER
Lincoln Drain - N
Lincoln Drain - S
West Drain
Kaiser Ditch
Morningside Drain
PERCENT TOTAL VOLATILE SOLIDS
1 LESS THAN 2
2 2-4
3 4-6
4 6-8
5 8-10
6 10-12
7 12-14
8 OVER 14
N
0
4000
FEET
METERS
0
1000
1
2
3
4
5
8
9
0

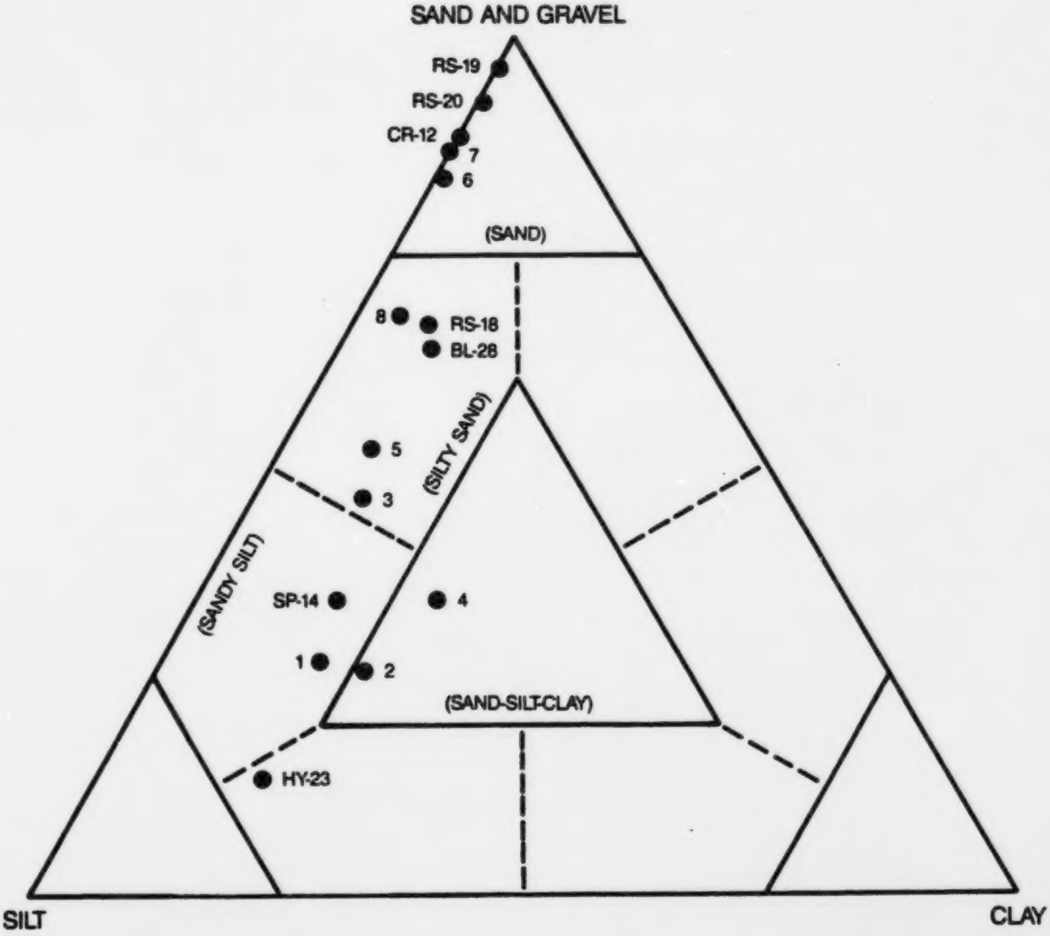
DOMINANT TAXA FOR EACH GROUP ARE LISTED IN TABLE 3.22.

Figure 3.34. Geographic distribution of station groups 1-9, plus outliers (o), in Commencement Bay waterways (from Figure 3.33). (Note: group boundaries are uncertain.)

TABLE 3.22. MEAN ABUNDANCES (No./m^2) OF NUMERICALLY DOMINANT TAXA AND MEAN VALUES OF SEDIMENT CHARACTERISTICS FOR THE MAJOR STATION GROUPS DEFINED BY NORMAL CLASSIFICATION ANALYSES (SEE FIGURE 3.33)

Station Group	Taxon	Abundance/m^2		Total Volatile Solids (%)		Total Organic Carbon (%)	
		$\bar{x}$	c.v.[a]	$\bar{x}$	c.v.	$\bar{x}$	c.v.
1	*Axinopsida serricata*	5,357	55.5	5.0	45.5	1.8	46.1
	Tharyx multifilis	4,837	64.3				
	Macoma carlottensis	745	75.3				
	Lumbrineris sp. gr. 1	612	67.4				
	Euphilomedes producta	348	86.7				
2	*Tharyx multifilis*	6,453	47.0	6.3	41.8	2.6	47.5
	Axinopsida serricata	1,362	63.9				
	Lumbrineris sp. gr. 1	438	40.8				
	Euphilomedes producta	242	47.4				
	Macoma carlottensis	135	45.0				
3	*Tharyx multifilis*	5,833	62.1	9.0	47.3	3.8	35.2
	Axinopsida serricata	603	79.4				
	Macoma carlottensis	378	18.9				
	Nephtys cornuta franciscana	220	52.8				
4	*Tharyx multifilis*	3,152	37.6	10.3	18.8	4.7	15.6
	Lumbrineris sp. gr. 1	252	29.3				
5	*Tharyx multifilis*	397	73.4	8.3	60.1	4.5	84.0
	Macoma carlottensis	192	81.0				
	Nephtys cornuta franciscana	148	87.6				
6	*Leptochelia dubia*	660	151.4	1.1	0.3	0.3	32.3
	Prionospio steenstrupi	315	72.4				
	Axinopsida serricata	288	94.8				
7	Mediomastus spp.	1,273	2.0	15.6	59.2	7.9	129.0
	Platynereis bicaniculata	808	56.0				
	Prionospio steenstrupi	707	86.0				
	Leptochelia dubia	453	53.0				
	Odostomia spp.	270	30.0				
	Tubificidae	210	1.0				
8	Nematoda	19,823	101.5	8.9	73.1	5.5	88.1
	Capitella capitata	4,548	37.8				
Outliers							
BL-28	*Axinopsida serricata*	1,258	--	1.9	--	0.7	--
	Tharyx multifilis	495	--				
	Macoma carlottensis	412	--				
	Lumbrineris sp. gr. 1	308	--				
CR-12	*Axinopsida serricata*	792	--	0.3	--	0.03	--
	Euphilomedes carcharodonta	420	--				
	Prionospio steenstrupi	325	--				
HY-23	*Axinopsida serricata*	217	--	10.5	--	3.8	--
	Tharyx multifilis	75	--				
RS-20	*Phyllochaetopterus prolifica*	337	--	1.5	--	0.3	--
	Polydora spp.	200	--				
RS-18	*Leptostylis villosa*	4	--	19.6	--	8.8	--
	Limnoria lignorum	4	--				
	Amphipholis squamata	4	--				
SP-14	Nematoda	45	--	44.3	--	1.6	--
	Tharyx multifilis	20	--				
RS-19	*Balanus crenatus*	775	--	1.0	--	0.6	--
	Cirratulus cirratus	470	--				
	Paleonotus bellis	217	--				

[a] c.v. = coefficient of variation.



DOMINANT SPECIES FOR STATION GROUPS ARE LISTED IN TABLE 3.22.

Figure 3.35. Sediment grain size characteristics of the major station groups defined by normal classification analysis of the benthic infaunal data in Commencement Bay study areas.

to bridge supports, the silty sand substrate found at that station, and the lower levels of organic materials (x=1.9 percent TVS, x=0.7 percent TOC) suggest that sediment scouring occurs there. Field observations of scoured sediments near these bridges indicate that passing barges have scraped bottom. Such physical disturbance may account for the differences observed between Station BL-28 and Station Groups 1 and 2.

Sediments near the terminus of Hylebos Waterway (Station Group 4) contained much greater quantities of organic materials (x=10.3 percent TVS, x=4.7 percent TOC) than did stations near the mouth (Station Groups 1 and 2). Faunal composition also changed. With the exception of Station HY-12 near the terminus of the Hylebos Waterway, *Tharyx mulifilis* dominated benthic communities in the upper third of the waterway, in the absence of high abundances of *Axinopsida serricata*.

Groups 3 and 5 and outlier Station HY-23 occur in the middle reaches of the Hylebos Waterway. Silty clay sediments were found at Station HY-23 and silty sand sediments were found at stations in Groups 3 and 5. The sediments of Groups 3 and 5 and Station HY-23 were characterized by relatively high levels of organic materials (x TVS=8.3-10.5 percent, x TOC=3.8-4.5 percent), as were the sediments of the upper waterway (Station Group 4). Station HY-23 and the stations in Group 5 were all characterized by low abundances of the dominant taxa. Abundances of *Axinopsida serricata* and *Tharyx multifilis* were particularly low at Station HY-23, averaging 13/m^2 and 75/m^2, respectively. Generally, abundances of *A. serricata* decreased and abundances of *T. multifilis* increased from the mouth of the waterway to the upper turning basin. Relative changes in the abundances of these two species along the waterway appear to have provided the discrimination between Groups 3, 4, and 5, and Station HY-23. Major changes in species composition were not apparent.

Group 6 included all Carr Inlet stations except CR-12, which was an outlier. Group 6 stations were characterized by sandy sediments with low organic levels (x=1.1 percent TVS, x=0.3 percent TOC). The tanaid *Leptochelia dubia*, the polychaete *Prionospio steenstrupi*, and the bivalve mollusc *Axinopsida serricata* were the numerical dominants in station Group 6. While *A. serricata* was abundant at many of the Commencement Bay waterway stations, *L. dubia* and *P. steenstrupi* were not. The abundance of these two latter species distinguishes Stations CR-11, CR-13, and CR-14 (Group 6).

Group 7 consisted of Stations RS-13 and RS-14 along the Ruston-Pt. Defiance Shoreline. Sediments at these two stations were highly enriched sands (x=15.6 percent TVS, x=7.9 percent TOC), and the benthic communities were dominated by the polychaetes *Mediomastus* spp. and *Platynereis bicaniculata*. These two species were not co-dominants at any other station sampled during the present study.

Group 8 consisted of only Station CI-11 at the head of City Waterway and Station SP-15 in the outer reaches of St. Paul Waterway. Both stations were dominated by nematodes and the polychaete *Capitella capitata*, which occured at very high abundances (combined abundances >8,000/m^2). Sediments at these two stations were silty sands with relatively high proportions of TVS (x=8.9 percent) and TOC (x=5.5 percent).

Faunal and sedimentary characteristics documented at Station SP-15 and CI-11 are better understood by comparisons with adjacent stations. In outer St. Paul Waterway, nearshore Station SP-14 (an outlier) exhibited very low abundances. Sediments at Station SP-14 were principally wood chips with silt, characterized by very high levels of organic materials (44.7 percent TVS, 16.0 percent TOC). Farther offshore at Station SP-15, sediments were primarily wood chips with sand, and organic materials were present at lower concentrations (8.9 percent TVS, 5.5 percent TOC). Sediments at Station SP-16 were sandy silt with yet lower concentrations of organic materials (3.6 percent TVS, 1.5 percent TOC). Coincident with the reductions in wood chips and quantities of organic materials from Station SP-14 to Station SP-16, abundances of infaunal organisms increased. Almost no organisms occurred at Station SP-14. Nematodes and the polychaete *Capitella capitata* were abundant and numerically dominant at Station SP-15, while farther offshore at Station SP-16, the bivalve mollusc *Macoma carlottensis* and the polychaete *C. capitata* were numerically dominant. Thus, there appears to have been a severe negative impact in the vicinity of Station SP-14, with conditions improving offshore. This impact also appears to have extended into the St. Paul Waterway as evidenced by the low abundances recorded at Stations SP-11 and SP-12. Sediments at Stations SP-11 and SP-12 were partially composed of wood chips and exhibited high concentrations of TVS (7.9-8.6 percent) and TOC (3.5-4.7 percent). As in most of the waterways, the polychaete *Tharyx multifilis* was numerically dominant. However, in contrast to the other waterways, it occurred only in low abundances, a possible indication of stress.

A similar gradation of sediment characteristics and species composition occurred along the length of City Waterway. Highest sediment organic levels occurred at Stations C-11, C-13, and C-16 (x=11.4-17.3 percent TVS, x=6.5-10.9 percent TOC). Nematodes and *Capitella capitata* dominated the communities at Stations C-11 and C-16, and were extremely abundant at Station C-11. As noted earlier, these taxa may reach high densities in areas of high organic enrichment. *Tharyx multifilis* occurred in place of nematodes and *C. capitata* at Stations C-13 and C-17. It occurred in much higher densities at Station C-17 (25,150/m^2) than at Station C-13 (1,433/m^2). Communities at these stations appeared to be transitional between those of Station CI-11 in the upper waterway and Stations CI-20 and CI-22 in the lower waterway. Lower waterway Stations CI-20 and CI-22 contained less organic material (x=3.2-8.5 percent TVS, x=1.2-4.6 percent TOC) in the sediments than did upper waterway Station CI-11 (13.5 percent TVS, 8.9 percent TOC) and were dominated by *Axinopsida serricata* and *T. multifilis*. Stations CI-20 and CI-22 were included in Group 1, which indicates that the communities in lower City Waterway were similar to those elsewhere in the waterways where organic enrichment was moderate and other possible sources of stress (e.g., toxic substances) apparently were not severe.

The four most unique stations sampled during the present survey were the outlier Stations HY-23, SP-14 (nearshore in the outer reaches of St. Paul Waterway), RS-18, and RS-19. All but Station RS-19 exhibited very low numerical abundances (<2,100/m^2). *Tharyx multifilis* and *Axinopsida serricata* were the two most abundant taxa at Station HY-23, but the remaining three stations were dominated by an assortment of polychaete, mollusc, and crustacean species that were absent, or occurred at very low abundances, at other stations in Commencement Bay and Carr Inlet (Figures 3.29-3.32). Very low numerical abundances, unique combinations of numerically dominant taxa, or both accounted for the uniqueness of these stations in the results of the classification analysis.

Sediment grain size characteristics at the low-abundance stations (i.e., Stations HY-23, SP-14, and RS-18) ranged from clayey silt to silty sand. TVS and TOC content of the sediments also varied considerably (3.7-19.6 percent and 1.6-8.8 percent, respectively). The only major common characteristic which these stations shared was greatly depressed abundances of benthic organisms compared with the other stations sampled during the study. As noted earlier, very reduced abundances indicate stressed conditions.

3.2.6 Animal-Sediment Relationships

As noted earlier, sediments were sandy along the Ruston-Pt. Defiance Shoreline and in Carr Inlet, whereas silty sands and sandy silts predominated in the waterways (Figure 3.35). Changes in water depth, volatile solids content (Figure 3.36), total organic carbon content (Figures 3.37, 3.38, 3.39), and the proportion of fine-grained materials (silt plus clay) in sediments (Figures 3.40, 3.41, and 3.42) were also evident within and among the study areas. While excess organic materials and other pollutants (e.g., toxic substances) affected species composition and abundance of benthic infauna within each study area, the affinities of benthic species for particular water depths and sediment habitats cannot be ignored.

The affinities of major taxonomic groups for particular sediment characteristics are clearly illustrated by the data in Figure 3.43. Total numerical abundances of all benthic species, polychaetous annelids, and molluscs are all significantly ($P<0.01$) correlated with the proportion of fine materials in the sediments.

Percent volatile solids, percent total organic carbon, percent sand, percent silt, and percent clay were all tested against abundances of the major taxonomic groups and selected dominant taxa. The grain size variables appeared to explain a substantial proportion of the variations in numerical abundances of benthic organisms (Table 3.23). Abundances of oligochaetes, amphipods, and *Prionospio* spp. were all positively correlated with percent sand and negatively correlated with percent silt or clay. Conversely, abundances of polychaetes, molluscs, *Lumbrineris* spp., *Axinopsida serricata*, and *Macoma carlottensis* were positively correlated with percent silt or silt plus clay, and negatively correlated with percent sand. Abundances of *Tharyx multifilis* were positively correlated only with percent clay, and were negatively correlated with percent sand.

It is apparent from these data (Figure 3.43, Table 3.23) that sediment grain size characteristics (or other factors with which these characteristics are highly correlated) are major determinants of benthic community structure. The importance of these factors relative to organic enrichment and the distribution of toxic substances in the sediments is difficult to demonstrate conclusively because sediment grain size characteristics vary considerably between the waterways and adjacent shoreline areas. Throughout the entire study area, the abundances of major taxa and dominant species appear to best reflect changes in grain size. But within each study area, the degree

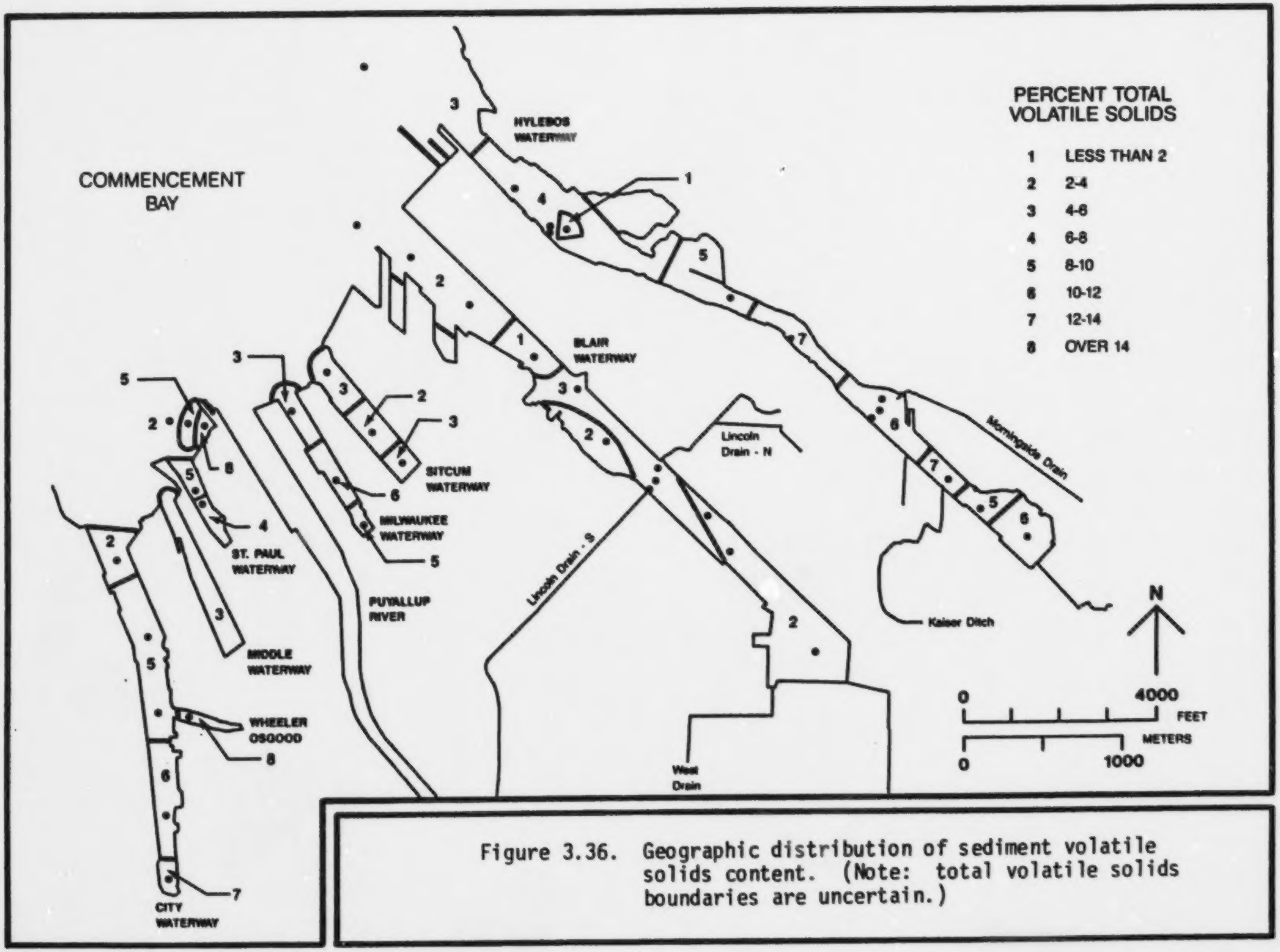

COMMENCEMENT BAY
PERCENT TOTAL VOLATILE SOLIDS
1 LESS THAN 2
2 2-4
3 4-6
4 6-8
5 8-10
6 10-12
7 12-14
8 OVER 14
HYLEBOS WATERWAY
BLAIR WATERWAY
SITCUM WATERWAY
MILWAUKEE WATERWAY
ST. PAUL WATERWAY
MIDDLE WATERWAY
WHEELER OSGOOD
CITY WATERWAY
PUYALLUP RIVER
Lincoln Drain - N
Lincoln Drain - S
West Drain
Kaiser Ditch
Morningside Drain
N
0
4000
FEET
METERS
0
1000

Figure 3.36. Geographic distribution of sediment volatile solids content. (Note: total volatile solids boundaries are uncertain.)

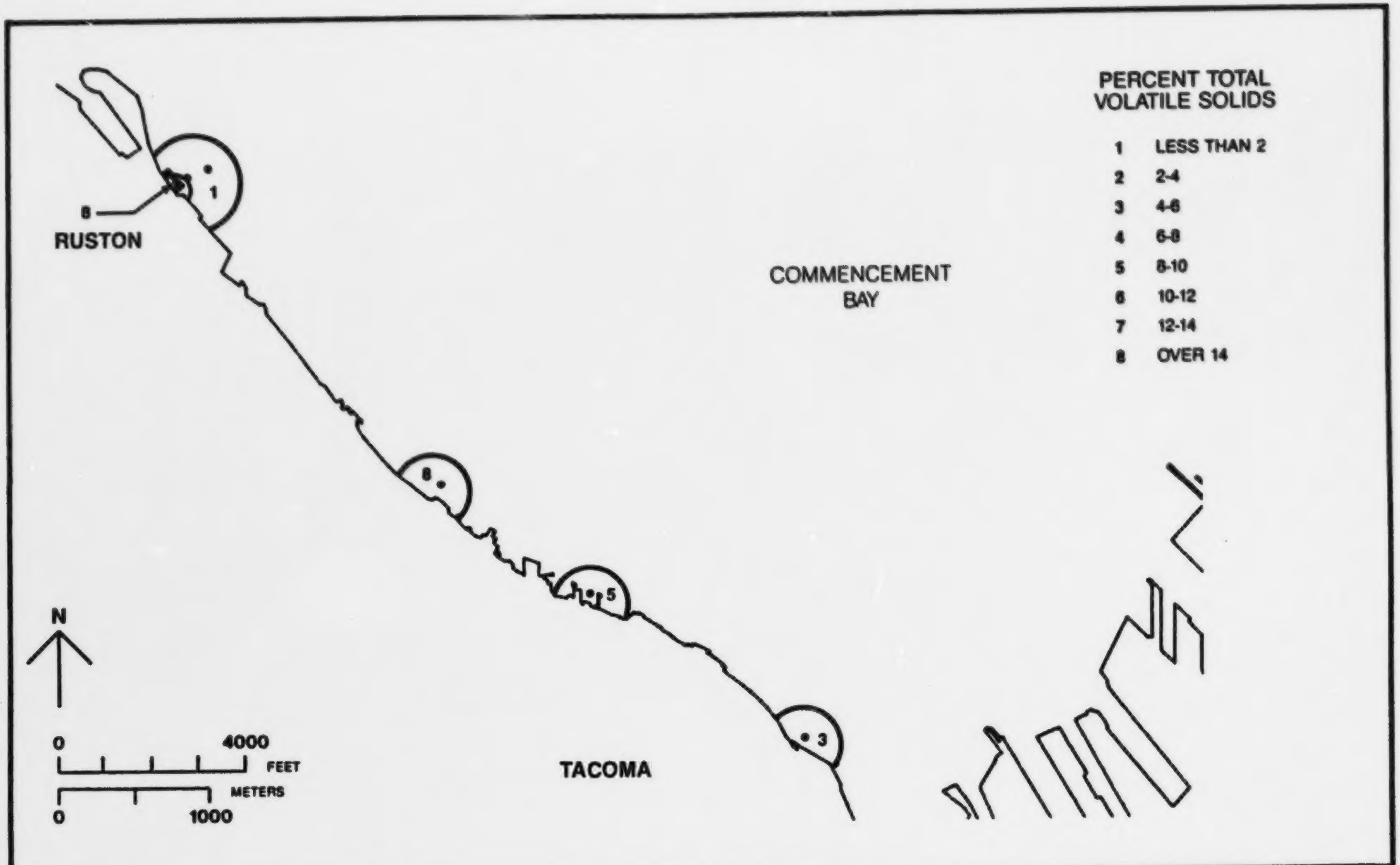

PERCENT TOTAL VOLATILE SOLIDS
1 LESS THAN 2
2 2-4
3 4-6
4 6-8
5 8-10
6 10-12
7 12-14
8 OVER 14
RUSTON
8
1
COMMENCEMENT BAY
8
5
3
TACOMA
N
0
4000
FEET
METERS
0
1000

Figure 3.36. (Continued)

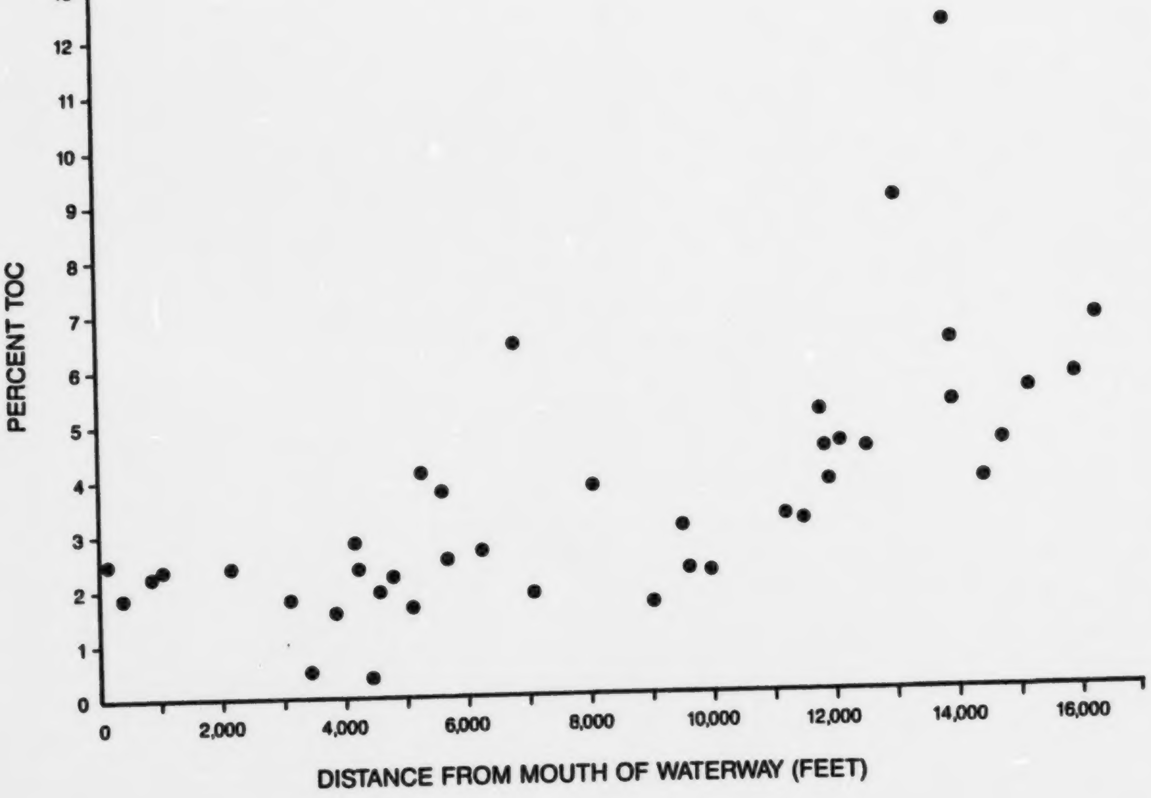


Figure 3.37. Total organic carbon content of the sediments in Hylebos Waterway.

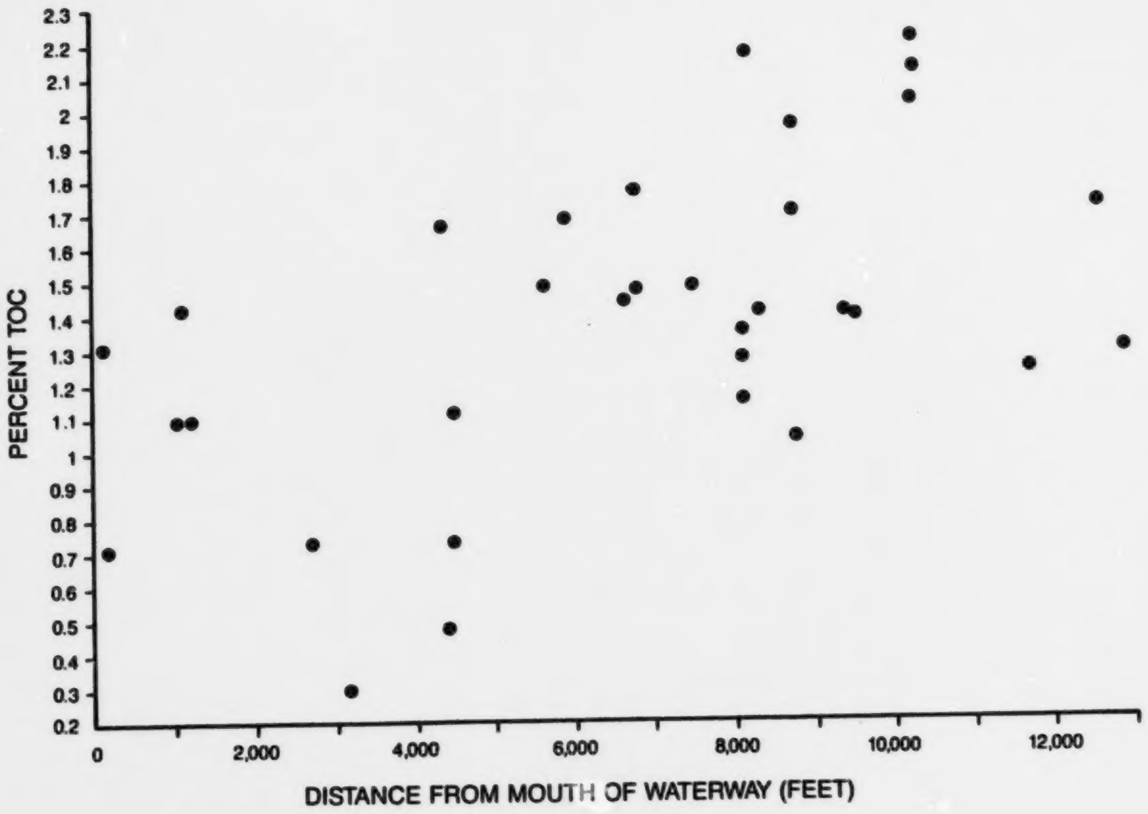


Figure 3.38. Total organic carbon content of the sediments in Blair Waterway.

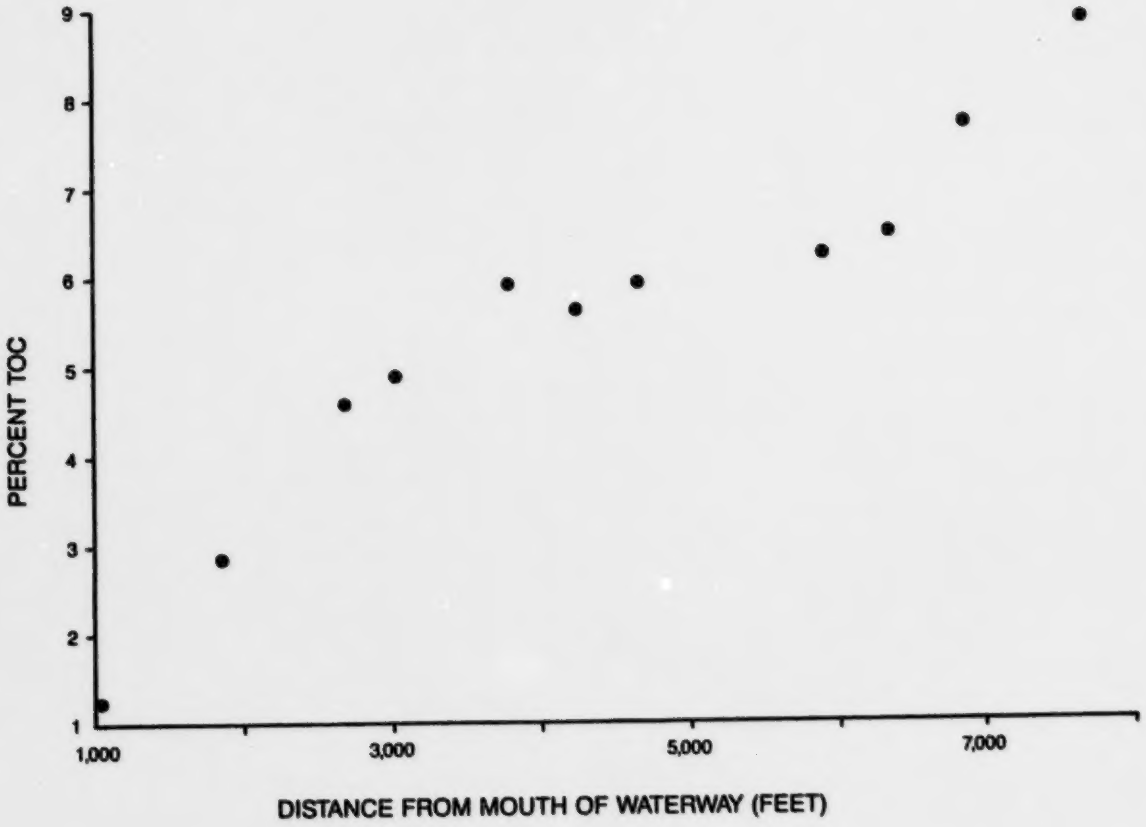


Figure 3.39. Total organic carbon content of the sediments in City Waterway.

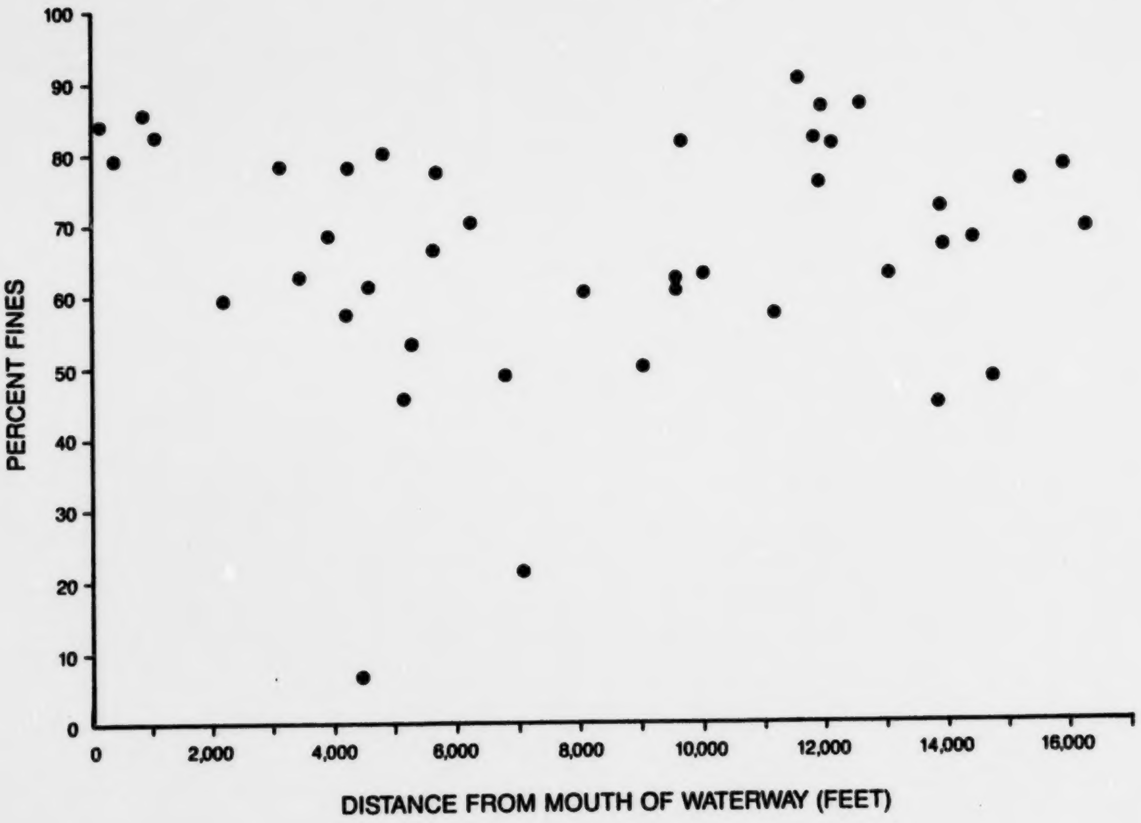


Figure 3.40. Percent fine-grained materials (silt plus clay) in the sediments of Hylebos Waterway.

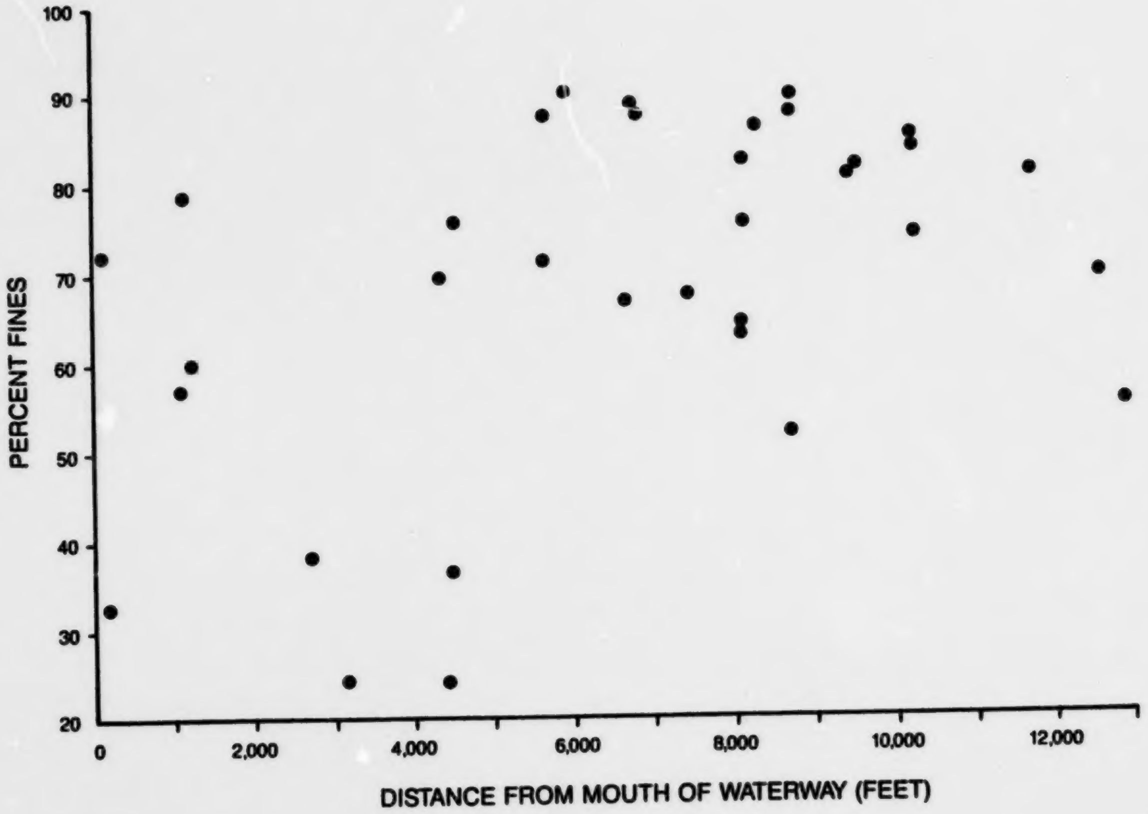


Figure 3.41. Percent fine-grained materials (silt plus clay) in the sediments of Blair Waterway.

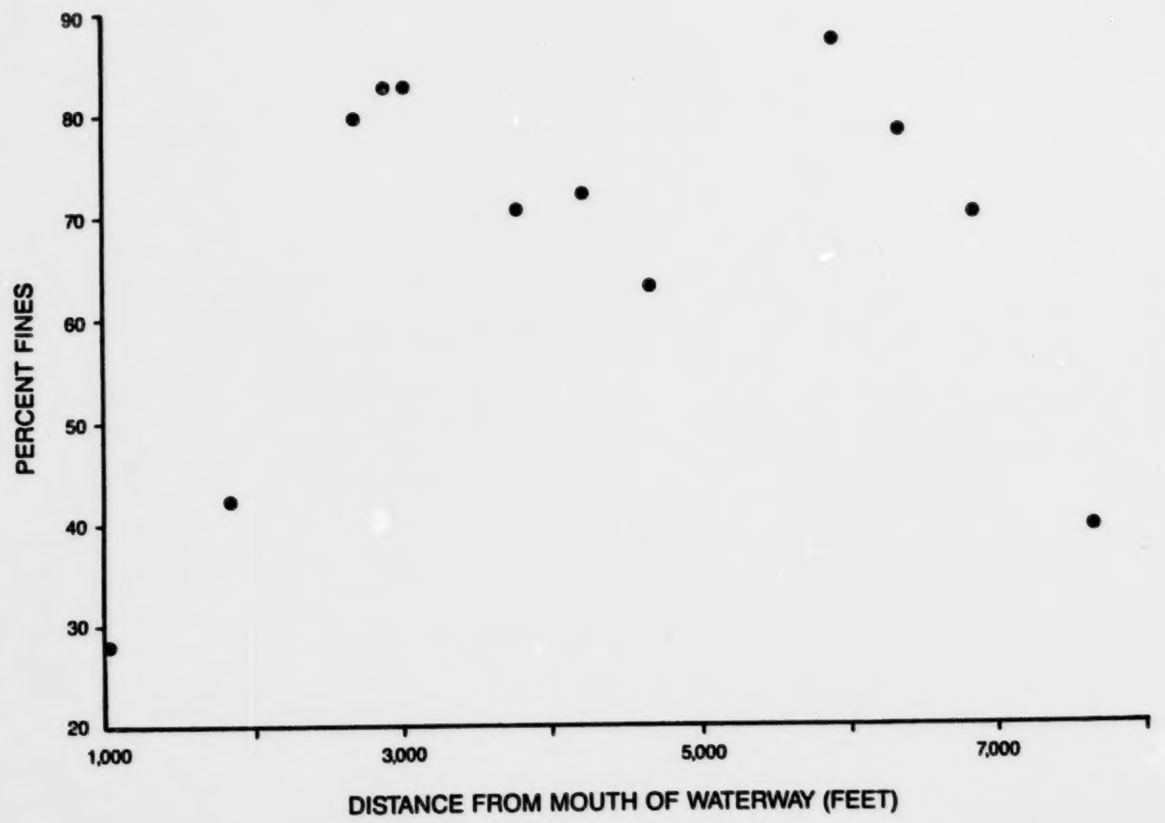


Figure 3.42. Percent fine-grained materials (silt plus clay) in the sediments of City Waterway.

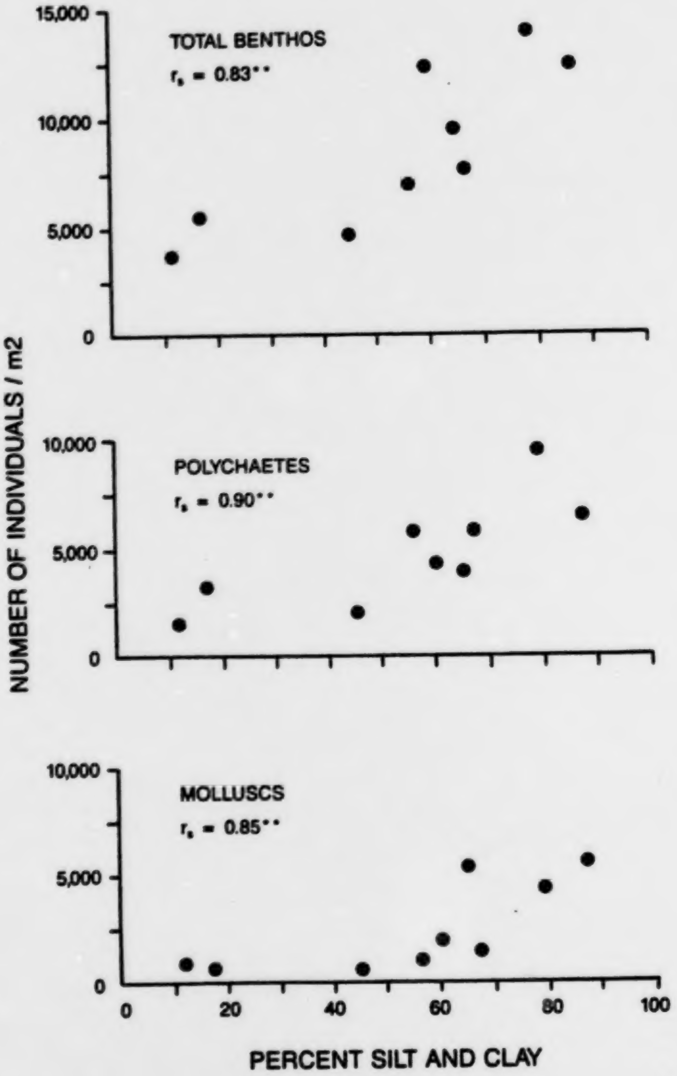


Figure 3.43. Correlations of numerical abundances of all benthic infauna, polychaetous annelids, and molluscs vs. the percent of fine-grained materials (silt plus clay) in the sediments (** = P<0.01).

TABLE 3.23. RESULTS OF PEARSON PRODUCT-MOMENT CORRELATION ANALYSES BETWEEN SEDIMENT CHARACTERISTICS, AND ABUNDANCES OF MAJOR TAXONOMIC GROUPS AND NUMERICALLY DOMINANT TAXA (RUSTON-PT. DEFIANCE SHORELINE AND CARR INLET STUDY AREAS DELETED)

Taxonomic Group	Sediment Variable			
or Taxon	% TOC[a]	% Sand	% Silt	% Clay
Polychaete abundance	ns	-*	+**	ns
Mollusc abundance	ns	-*	+**	ns
Oligochaete abundance	ns	+*	-*	ns
Amphipod abundance	ns	+**	-**	-**
Prionospio spp.	+*	ns	ns	ns
Lumbrineris spp.	ns	-**	+**	+*
Tharyx multifilis	ns	-**	ns	+*
Axinopsida serricata	ns	-*	+**	ns
Macoma carlottensis	ns	-*	+*	ns

[a] TOC = Total organic carbon.

[b] ns = Not significant at an experimentwise error rate of $P<0.05$ (i.e., an error rate of $P<0.0125$ for each test).

[c] * = $P<0.125$; ** = $P<0.0025$; + = positive correlation; - = negative correlation.

of organic enrichment appears to explain better much of the variation in community structure and abundance.

Data from Blair, Hylebos, and City Waterways illustrate this point well. The proportions of fine-grained sediments (silt plus clay) exhibited large fluctuations (more than 60 percentage points) along the lengths of all three waterways (Figures 3.40, 3.41, 3.42). The proportions of total organic carbon in the sediments also varied considerably in Hylebos and City Waterways, but not in Blair Waterway (Figures 3.37, 3.38, 3.39). Total organic carbon ranged from 3.1 to 12.2 percent in Hylebos Waterway and from 1.2 to 8.9 percent in City Waterway, but only from 0.6 to 2.2 percent in Blair Waterway.

If grain size were the most important determinant of benthic community structure within each of the waterways, dramatic changes in community structure would have been evident along the lengths of all three waterways. However, as discussed earlier, benthic community structure was very similar along the length of Blair Waterway (Figure 3.30). Abundances of the dominant species changed, but species composition did not. In Hylebos and City Waterways, species composition and numerical abundances changed greatly (Figures 3.29, 3.30), and in a pattern consistent with gradients of organic enrichment of sediments, wherein values decreased from the heads to the mouths of the waterways (see earlier discussion). Thus, organic content of the sediments appeared to account for a considerable amount of faunal variation within many of the waterways. Among the waterways, however, changes in sediment grain size appeared to be the major determinant of benthic community structure.

3.2.7 Indices for Decision Criteria

3.2.7.1 Introduction--

To develop indices of benthic degradation for use as decision criteria, abundances of major benthic invertebrate taxa at potentially impacted sites were compared statistically with their respective abundances at reference sites. A statistically significant decrease ($P<0.05$) in the abundance of an indicator taxon was considered a benthic impact (i.e., a benthic depression). At each station, indicies were based on the abundance of the total assemblage (i.e., total taxa) and on the abundances of polychaetes, molluscs, and crustaceans. As a group, polychaetes, molluscs, and crustaceans accounted for approximately 91 percent of the individuals sampled at the 48 study sites throughout Commencement Bay and Carr Inlet in March, 1984. Echinoderms and other miscellaneous taxa were not included as indices because they were rarely encountered during the study.

3.2.7.2 Reference Site Selection--

Sediment characteristics at Carr Inlet stations were similar to those at stations along the Ruston-Pt. Defiance shoreline, but were considerably different from those at most stations in the Commencement Bay waterways. For example, percent fine-grained sediments (silt and clay) in Carr Inlet and the Ruston-Pt. Defiance Shoreline exhibited ranges of 4-23 and 3-33 percent, respectively. By contrast, percent fine-grained sediments at all Commencement Bay waterway stations except Station HY-44 (6 percent) ranged from 26 to 89 percent. Because abundances of total assemblages, polychaetes, and molluscs were positively correlated ($P<0.05$) with percent fine-grained sediments (see Figure 3.43, Section 3.2.6), sediment character was a confounding variable for evaluating contaminant effects. That is, differences between benthic assemblages in Carr Inlet and assemblages at Commencement Bay waterway stations muddier than Carr Inlet stations could result from either contamination or differences in sediment character. Benthic assemblages in Carr Inlet were therefore considered acceptable reference conditions for stations along the Ruston-Pt. Defiance shoreline, but inadequate as reference conditions for all Commencement Bay waterway stations except Station HY-44.

Because Carr Inlet could not be used as a valid reference area for Commencement Bay waterway stations, Blair Waterway was substituted as a best estimate of unimpacted waterway conditions. This waterway was selected because 1) it was the least contaminated chemically of the seven waterways (Section 3.1); 2) only one significant bioassay result (i.e., amphipod mortality at Station BL-25) was found out of the twelve tested (i.e., amphipod mortality and oyster larvae abnormality at six stations) in March, 1984 (Section 3.3); and 3) percent fine-grained sediment at Blair Waterway stations spanned a range (37-84 percent) similar to that observed for all waterway stations except Station HY-44 (26-89 percent). Thus, all Blair Waterway stations except Station BL-25 exhibited relatively low chemical contamination, no toxicity, and sediment characteristics similar to those found throughout the other waterways.

To help remove the confounding effects of sediment character, Blair Waterway stations were divided into three groups representing different ranges of sediment characteristics. Station BL-25 was not used in this analysis because a toxic response (amphipod mortality) was found at that site. Reference conditions with which potentially affected stations were compared are presented in Table 3.24. Note that Station HY-44 was compared with Carr Inlet sites.

3.2.7.3 Statistical Comparisons--

Log-transformed abundances of total assemblages, polychaetes, molluscs, and crustaceans were compared between potentially impacted and reference sites using the t-test. Before each t-test was conducted, an F_{max} test was used to test for equality of variances. For comparisons in which variances were not equal ($P<0.05$), an approximate t-test (Sokal and Rohlf 1969) was used to compare mean values.

Comparisons of the four major taxa at the 39 potentially impacted stations sampled in Commencement Bay in March, 1984 are summarized in Table 3.25. A benthic invertebrate taxon was considered numerically depressed if its mean abundance at a potentially impacted station was statistically significantly lower ($P<0.05$) than its mean abundance at the appropriate reference station(s) (see Table SB30), or if it was absent from the potentially impacted site. For the two stations at which a major taxon was absent (SP-14 and RS-18), a t-test could not be conducted because the variances equalled zero. However, if even a single individual had been captured, the mean abundance would have differed significantly ($P<0.05$) from reference

TABLE 3.24. PAIRINGS OF REFERENCE STATIONS AND POTENTIALLY IMPACTED STATIONS USED FOR STATISTICAL COMPARISONS

Reference Station(s)	Range of % Fines[a]	Potentially Impacted Stations	Range of % Fines[a]
BL-28	37	SP-11, SP-12, SP-15 CI-11, CI-22 HY-14	26-49
BL-11	55-64	SP-14, SP-16, CI-13, CI-16, CI-17, CI-20 HY-12, HY-17, HY-22, HY-28, HY-32, HY-37, HY-42, HY-43, HY-47 SI-11, SI-12 MD-12	55-80
BL-13	84	HY-23, HY-24, HY-50 SI-15 MI-11, MI-13, MI-15 BL-25	81-89
CR-11 CR-12 CR-13 CR-14	4-23	RS-12, RS-13, RS-14 RS-18, RS-19, RS-20 HY-44	3-33

[a] Silt and clay.

TABLE 3.25. COMPARISONS OF MEAN ABUNDANCES OF BENTHIC INVERTEBRATE TAXA BETWEEN POTENTIALLY IMPACTED STATIONS AND REFERENCE STATIONS[a]

Potentially Impacted Station	Total	Polychaeta	Taxon Mollusca	Crustacea	Total Depressions
HY-12					0
HY-14			*		1
HY-17			*	*	2
HY-22			*	*	2
HY-23	*[b]	*	*		3
HY-24					0
HY-28					0
HY-32	*		*	*	3
HY-37			*		1
HY-42					0
HY-43					0
HY-44					0
HY-47			*		1
HY-50					0
BL-25					0
SI-11				*	1
SI-12				*	1
SI-15					0
MI-11					0
MI-13					0
MI-15					0
SP-11					0
SP-12					0
SP-14	*	0[c]	*	*	4
SP-15			*	*	2
SP-16	*				1
MD-12					0
CI-11			*		1
CI-13	*	*	*	*	4
CI-16	*	*	*	*	4
CI-17					0
CI-20					0
CI-22					0
RS-12					0
RS-13					0
RS-14					0
RS-18	*	0	0	*	4
RS-19			*		1
RS-20			*		1

[a] Reference stations are listed in Table 3.24.

[b] An asterisk denotes that mean abundance of a major taxon at a potentially impacted station was significantly lower ($P<0.05$, experimentwise) than mean abundance at the reference station(s) (i.e., a benthic depression).

[c] 0 = A major taxon was absent from a potentially impacted station (i.e., a benthic depression).

conditions. Therefore, absence of a major taxon was considered as severe as a significantly depressed ($P<0.05$) abundance.

No benthic depressions were found at stations in Middle and Milwaukee Waterways. In Sitcum Waterway, single depressions (Crustacea) were found at two of the three stations (SI-11 and SI-12). The remaining four study areas (Hylebos, St. Paul and City Waterways, and the Ruston-Pt. Defiance Shoreline) included stations with multiple benthic depressions.

In Hylebos Waterway, a cluster of stations (HY-17, HY-22, and HY-23) with multiple benthic depressions was found near the head of the waterway. In addition, a single station (HY-32) with multiple depressions was found farther down the waterway.

In St. Paul Waterway, multiple benthic depressions were found at the two stations (SP-14 and SP-15) located closest to the Champion International paper mill. Polychaetes were absent from the station located closest to the mill (SP-14). In addition, the number of depressions per station showed a decreasing gradient with distance from the mill. No depressions were found at stations located within the waterway proper.

In City Waterway, stations with multiple depressions were found near the head of the waterway (CI-13) and in the Wheeler Osgood branch (CI-16). No benthic depressions were found at the mouth of the waterway.

Along the Ruston-Pt. Defiance Shoreline, multiple benthic depressions were found only at the station located closest to ASARCO (RS-18). Two taxa (Polycheata and Mollusca) were absent from that station. No benthic depressions were found at any of the three stations located southeast of ASARCO (RS-12, RS-13, and RS-14).

Of the invertebrate taxa used as indices in the foregoing analysis, Mollusca was the most sensitive indicator of benthic impacts, with 15 of the 39 stations showing depressed abundances of this taxon. Crustacea ranked second relative to impact sensitivity, with depressions at 10 stations. Finally, total taxa and Polychaeta were the least sensitive indicators of impacts, with depressions found at only seven and five stations, respectively.

3.2.8 Comparisons with Past Studies

The only benthic infaunal sampling undertaken along the Ruston-Pt. Defiance Shoreline or in the Commencement Bay Waterways that is capable of providing data for long-term comparisons was conducted by Orlob et al. (1950) during the summer of 1950. The utility of those data for comparisons with present conditions is severely limited for several reasons. First, the size of the sampler was not stated and replicates were apparently not collected at each station. Second, although samples were washed on screens, the mesh size was not stated. Third, only some of the organisms in the samples were retained for identification. These limitations preclude quantitative comparisons with present biological conditions. However, some of the qualitative observations made by Orlob et al. (1950) are informative.

In general, Orlob et al. (1950) collected reasonably diverse assemblages of benthic organisms along most of the Ruston-Pt. Defiance Shoreline, with the exception of the area near ASARCO (Station RS-18 from the present study). No living benthic organisms were collected there in 1950 and only very low numbers of benthic organisms were collected during the present study. Reasonably diverse assemblages were also collected at the mouths of major waterways. However, sampling along the lengths of the Hylebos and City Waterways failed to collect any benthic macroinvertebrates in the upper reaches of either waterway. Orlob et al. (1950) attributed the apparent lack of benthic organisms in the upper Hylebos Waterway to "domestic sewage and industrial wastes from various plants, including two large chemical firms." The lack of benthic invertebrates in the upper City Waterway was attributed to wastes from a meat packing plant. Sediments in this area exuded a strong odor of hydrogen sulfide, which is consistent with extreme organic enrichment.

Although conditions in the vicinity of Station RS-18 do not appear to have improved during the 34-yr interval, some improvement in upper Hylebos and City Waterways seems to have occurred, as these areas are no longer devoid of benthic life. However, due to the very sketchy nature of the data collected by Orlob et al. (1950), no other conclusions regarding temporal changes are appropriate.

3.2.9 Summary

- Benthic assemblages in the Commencement Bay waterways are distinct from assemblages in Carr Inlet and the Ruston-Pt. Defiance Shoreline, as evidenced by reduced numbers of species, high dominance, and enhanced total abundances within the waterways

- Overall benthic community characteristics in the waterways are indicative of environmental stress that may be associated with toxic contamination, sediment disturbance, or physical characteristics (e.g., grain size) of the sediments. However, the overall high abundances of a mixed polychaete-mollusc assemblage indicate that any broad-scale stresses are not sever.

- A characteristic *Tharyx*-*Axinopsida* assemblage occurred throughout much of the waterway area, including Blair, Sitcum, and Milwaukee Waterways, the mouth of City Waterway, and the mouth of Hylebos Waterway.

- Within many of the waterways, organic content of the sediments appears to account for a considerable amount of faunal variation. Among the waterways, changes in sediment grain size appear to be the major determinant of benthic community structure.

- Excessive organic enrichment of sediments appears to have been occuring at some stations where nematodes and the polychaete *Capitella capitata* exhibited very high abundances (relative to the Tharyx-Axinopsida community and communities in the control area), and comprised most of the organisms collected.

- Stresses other than those resulting from organic enrichment appear to have been occurring at a few stations in the waterways and along the Ruston-Pt. Defiance Shoreline where total abundances were very depressed (relative to the Tharyx-Axinopsida community and communities in the control area).

- Abundances of major benthic invertebrate taxa (i.e., total abundance, Polychaeta, Mollusca, and Crustacea) were not depressed significantly ($P<0.05$) at any station in Middle or Milwaukee Waterways. In Sitcum Waterway, single depressions (Crustacea) were found at two of three stations.

- Multiple benthic depressions were found in Hylebos, St. Paul, and City Waterways, and along the Ruston-Pt. Defiance Shoreline. Areas having multiple depressions included the head of Hylebos Waterway (HY-17, HY-22, and HY-23), the middle of Hylebos Waterway (HY-32), the stations closest to Champion International (SP-14 and SP-15), the head of City Waterway (CI-13), the Wheeler Osgood branch of City Waterway (CI-16), and the station closest to ASARCO (RS-18).

- Spatial patterns of benthic depressions are presented in Figure 3.44.

- Benthic biological conditions do not appear to have improved in the vicinity of Station RS-18 since it was first sampled in 1950. Some improvement does appear to have occurred at the head of Hylebos and City Waterways during this time interval.

3.3 SEDIMENT TOXICITY

3.3.1 Introduction

Sediment toxicity tests were conducted as part of the Commencement Bay Investigations to determine if laboratory exposures of the sediments were acutely toxic to representative organisms. The degree of sediment toxicity was used in the decision-making approach as one of the indicators to identify and prioritize problem areas.

Two separate test procedures were conducted on each sediment sample: the amphipod mortality bioassay and the oyster larvae abnormality bioassay. The amphipod bioassay was used to measure a direct lethal response. Partial life-cycle tests with oyster larvae were used to measure the induction of abnormal development in developing embryos after a 48-h exposure to sediments. Significant oyster larvae abnormalities compared to controls are indicative of chemical toxicity (Cardwell et al. 1979; Chapman and Morgan 1983). Data on the relative survival of exposed oyster larvae were also collected to aid in the interpretation of abnormality data.

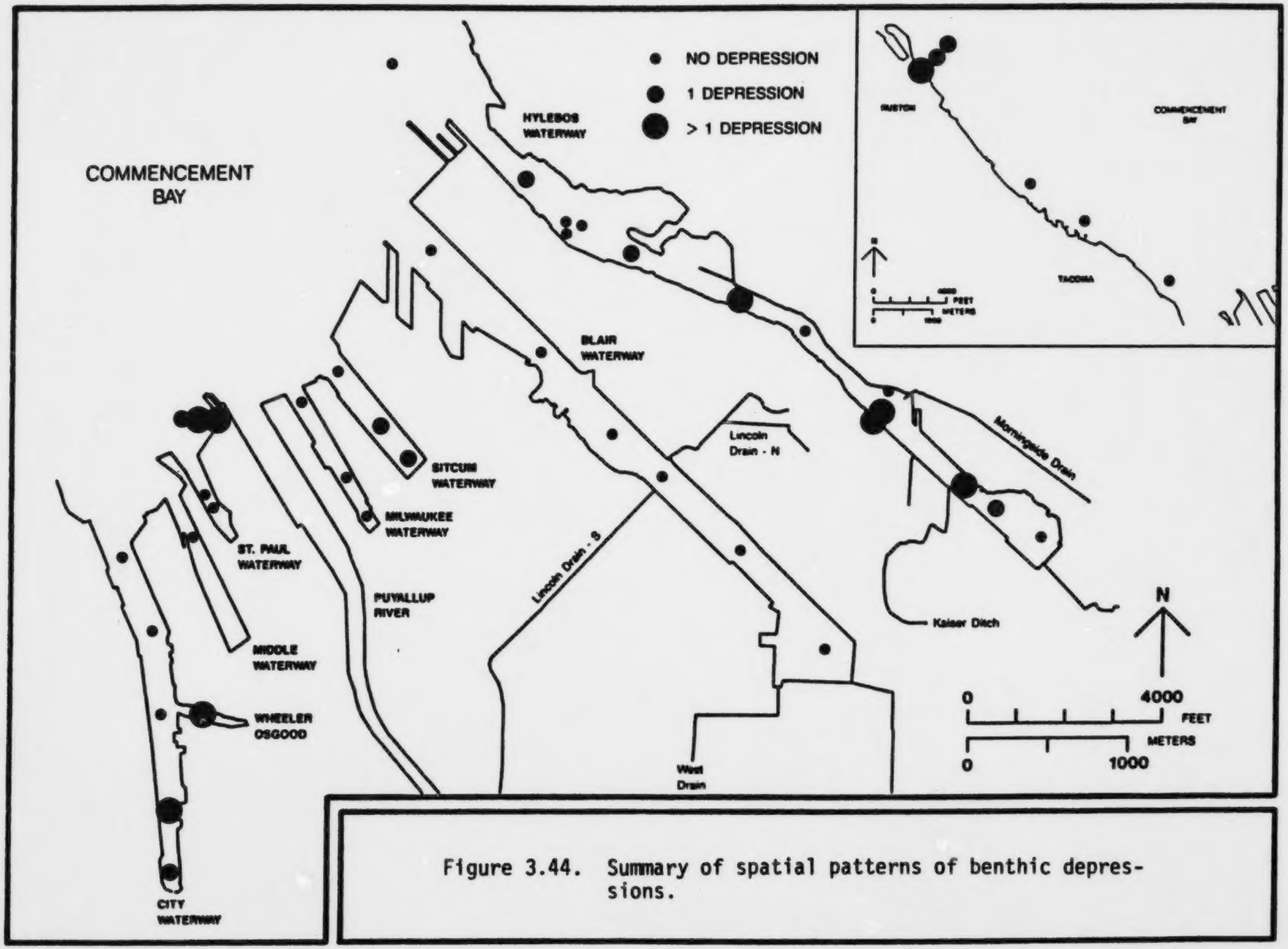

NO DEPRESSION
1 DEPRESSION
> 1 DEPRESSION
COMMENCEMENT BAY
HYLEBOS WATERWAY
BLAIR WATERWAY
SITCUM WATERWAY
MILWAUKEE WATERWAY
PUYALLUP RIVER
ST. PAUL WATERWAY
MIDDLE WATERWAY
WHEELER OSGOOD
CITY WATERWAY
Lincoln Drain - N
Lincoln Drain - S
West Drain
Morningside Drain
Kaiser Ditch
N
0
4000
FEET
METERS
0
1000
RUSTON
COMMENCEMENT BAY
TACOMA

Figure 3.44. Summary of spatial patterns of benthic depressions.

The bioassays were conducted on intact sediment samples (i.e., non-dilution tests) and on sediment samples diluted with clean (i.e., reference) sediments (i.e., dilution bioassays).

3.3.2 Amphipod Sediment Bioassays

3.3.2.1 Non-Dilution Bioassays--

Results of the non-dilution amphipod bioassay tests are summarized in Table 3.26. Clean sediment control mortality values ranged from 4 to 10 percent; a mean mortality of 10 percent is considered acceptable for amphipod sediment bioassay controls (Swartz et al. 1985). Mortality in Cd-spiked sediments was 94 percent, which is consistent with the expected mortality rate.

ANOVA indicated no significant difference ($P>0.05$) in mean mortality values among the clean sediment controls. Results for Commencement Bay sediments were compared with those for the reference area (Carr Inlet) using the t-test. One reference sediment sample had an exceptionally high amphipod mortality (CR-11; mean mortality = 25 percent), that was significantly higher than mortalities in the other three reference samples. The overall low survival resulted from a high mortality in only one of the five replicates at this station. Consequently, this sample was deleted from the statistical comparisons. The subsequent analysis indicated that mortalities in 18 test sediments were significantly different ($P<0.05$, experimentwise error rate) from the Carr Inlet samples.

3.3.2.2 Dilution Bioassays--

Results of the amphipod sediment dilution bioassays are summarized in Table 3.27. Results indicate that for five of the six sediments tested, a 25 to 50 percent concentration of test sediment (i.e., a 50 to 75 percent dilution) was sufficient to eliminate the toxic response. The only exception was combined sediment from Stations RS-18 and RS-19, which was still highly toxic at the lowest test sediment concentration (10 percent) assayed.

Comparison of the initial (non-dilution) bioassays on these sediments with results of the 100 percent test sediment concentration for the dilution bioassays indicated a high level of agreement (Table 3.28). The only exception was sediment from Station CI-11, which initially gave a mean mortality of 52.0 percent, and subsequently gave a mean value of 25.0 percent. This difference is most probably due to a reduction in toxicity with storage, a phenomenon documented by Cummins (Cummins, J., January, 1983-February, 1984, personal communication). Test sediments used for dilution bioassays were stored for approximately 1 mo after collection.

3.3.3 Oyster Larvae Sediment Bioassays

3.3.3.1 Non-Dilution Bioassays--

Results of the non-dilution oyster larvae bioassay tests are summarized in Table 3.29. In addition to larval numbers, oyster embryo response is expressed in terms of mean percent abnormal larvae and mean percent mortality (compared to clean seawater controls). Salinity, pH, and dissolved oxygen

TABLE 3.26. SUMMARY OF NON-DILUTION AMPHIPOD BIOASSAY RESULTS

Station	Percent Mortality[a]	Station	Percent Mortality[a]
HY-12	16	CI-11	52*
HY-14	9	CI-13	20
HY-17	19	CI-16	14
HY-22	36*	CI-17	17
HY-23	26*	CI-20	30*
HY-24	19	CI-22	19
HY-28	8		
HY-32	20	RS-12	15
HY-37	18	RS-13	32*
HY-42	37*	RS-14	20
HY-43	19	RS-18	95*
HY-44	15	RS-19	77*
HY-47	25	RS-20	5
HY-50	16	RS-22	10
		RS-24	28*
B-03	16		
B-04	13	CR-11	25
B-19	19	CR-12	11
B-10	20	CR-13	7
BL-11	13	CR-14	10
B-12	20		
BL-13	19		
B-15	27*		
BL-21	14	Controls	
BL-25	28*	Clean	
BL-28	8	Sediment	
BL-31	16		
		a	4
SI-11	24	b	7
SI-12	31*	c	8
SI-15	25*	d	4
		e	10
MI-11	24*	f	8
MI-13	14	g	9
MI-15	20*		
SP-11	12	Cd-Spiked	
SP-12	16	Sediment	94
SP-14	100*b		
SP-15	68*		
SP-16	27*		
MD-12	13		

[a] Percent mortality is based on five replicate samples per station. Asterisk denotes that mean mortality was significantly different ($P<0.05$ experimentwise) from the mean mortality of pooled replicates from CR-12, CR-13, and CR-14 (i.e., 9.3 percent, n=15).

[b] Because 100 percent mortality occurred for all five replicates at SP-14, no variance about the mean existed and a t-test could not be conducted. However, the observed level of mortality was considered at least as severe as the levels determined to be significant ($P<0.05$) at other sites.

TABLE 3.27. SUMMARY OF AMPHIPOD SEDIMENT DILUTION BIOASSAYS

		Percent Mortality		
Station Number	Test Sediment Concentration[a]	N[b]	Mean	SD
HY-22	100	5	31.0	2.6
HY-22	75	5	26.0	2.8
HY-22	50	5	25.0	2.3
HY-22	25	5	18.0	1.8
HY-22	10	5	20.0	2.0
HY-22	0	5	10.0	2.0
HY-42	100	5	35.0	2.4
HY-42	75	5	27.0	0.9
HY-42	50	5	26.0	2.4
HY-42	25	5	9.0	1.8
HY-42	10	5	7.0	1.7
HY-42	0	5	3.0	0.9
BL-25[c]	100	ND[d]	ND	ND
BL-25	75	1	25.0	N/A
BL-25	50	2	7.5	0.7
BL-25	25	3	10.0	1.0
BL-25	10	2	12.5	0.7
BL-25	0	3	10.0	1.0
SP-14	100	4	100.0	0
SP-14	75	4	100.0	0
SP-14	50	4	97.5	0.6
SP-14	25	4	21.0	2.9
SP-14	10	4	18.5	1.9
SP-14	0	4	8.5	0.5
CI-11	100	5	25.0	2.5
CI-11	75	5	21.0	1.8
CI-11	50	5	13.0	2.3
CI-11	25	5	25.0	2.6
CI-11	10	5	17.0	2.3
CI-11	0	5	7.0	0.9
RS-18/19[c,e]	100	ND	ND	ND
RS-18/19	75	2	100.0	0
RS-18/19	50	2	90.0	1.4
RS-18/19	25	3	98.5	0.6
RS-18/19	10	3	55.0	2.6
RS-18/19	0	3	8.5	1.2

[a] Percent of test sediments mixed with West Beach control sediments. The 0-percent concentration contains only control sediments

[b] Number of replicate bioassays conducted at each sediment dilution. Each replicate bioassay was performed with 20 amphipods.

[c] Insufficient sediments for these samples for five replicate at each sediment concentration.

[d] ND = No data.

[e] Samples RS-18 and RS-19 were combined due to a lack of sediments.

TABLE 3.28. COMPARISONS OF INITIAL AND DILUTION BIOASSAYS FOR AMPHIPOD MORTALITY AND OYSTER LARVAL ABNORMALITY

	Percent Amphipod Mortality		Percent Oyster Abnormality	
Station	Initial	Dilution[a]	Initial	Dilution[a]
HY-22	36.0	31.0	39.0	ND
HY-42	37.0	35.0	29.2	33.8
BL-25	28.0	ND[b]	19.9	35.3
SP-14	100.0	100.0	100.0[c]	100.0[c]
CI-11	52.0	25.0	63.0	40.6
RS-18/19	86.0[d]	ND	58.1	62.3
Seawater Control	NA[e]	NA	4.1	6.9
Sediment Control	NA	NA	10.1	8.1

[a] Assay response to 100-percent test sediments (i.e., 0-percent control sediments).

[b] ND = no data.

[c] Nominally 100 percent abnormality since there was 100 percent mortality.

[d] Mean of RS-18 and RS-19 bioassay results.

[e] NA = not applicable.

TABLE 3.29. SUMMARY OF NON-DILUTION OYSTER LARVAE BIOASSAY RESULTS

Station	Mean Number of Larvae[a]	Percent Relative Mortality[b]	Percent Abnormality[c]
HY-12	40	46	45.6*
HY-14	148	64	25.4
HY-17	75	82	41.0*
HY-22	62	85	39.0*
HY-23	70	83	35.5*
HY-24	173	58	24.7
HY-28	109	73	22.8
HY-32	124	70	23.8
HY-37	117	71	22.5
HY-42	89	78	29.2
HY-43	167	59	21.3
HY-44	146	64	15.5
HY-47	110	73	32.4*
HY-50	129	69	26.4
B-03	55	40	13.4
B-04	36	61	24.3
B-09	47	49	20.2
B-10	25	73	30.2
BL-11	230	44	17.5
B-12	31	66	17.8
BL-13	115	72	21.0
B-15	35	62	26.1
BL-21	157	62	22.9
BL-25	128	69	19.9
BL-28	165	60	15.9
BL-31	178	57	18.1
SI-11	203	51	16.0
SI-12	179	56	18.1
SI-15	156	62	16.2
MI-11	182	56	22.6
MI-13	147	64	16.1
MI-15	165	60	16.8
SP-11	163	60	20.7
SP-12	122	70	29.9*
SP-14	1	99	100.0*
SP-15	54	87	61.9*
SP-16	64	84	36.0*
MD-12	136	67	23.7

TABLE 3.29. (Continued)

CI-11	85	79	63.0*
CI-13	77	81	31.9*
CI-16	78	81	32.2*
CI-17	148	64	22.0
CI-20	70	83	31.6*
CI-22	179	56	20.3
RS-12	152	63	21.9
RS-13	111	73	30.1
RS-14	178	57	18.1
RS-18	37	91	69.6*
RS-19	97	76	46.5*
RS-20	240	42	8.6
RS-22	256	38	8.5
RS-24	146	64	21.3
CR-11	175	57	16.8
CR-12	203	51	11.3
CR-13	191	53	9.9
CR-14	180	56	14.3
Seawater control	411	-	4.1
Sediment control	313	24	10.1

[a] Numerals are the mean numbers of larvae used to determine abnormalities. Means are based on duplicate tests for all field stations and on five tests for the seawater and sediment controls.

[b] Percent of larvae that died before test was terminated, in terms of the mean seawater control mortality which was assigned a value of 0 percent.

[c] Percent of larvae showing developmental abnormalities. Asterisks denote values significantly different ($P<0.05$ experimentwise) from that observed in Carr Inlet (i.e., CR-11, CR-12, CR-13, and CR-14 pooled).

remained at acceptable levels [as defined by ASTM (1983): pH range 7.3-8.3; salinity range 20-35 ppt; dissolved oxygen range 4-12 mg/L] in most test containers, including those eliciting adverse larval response (pH range 7.3-8.0; salinity range 27.5-28.5; dissolved oxygen range 4.0-7.8 mg/L). The only exceptions were samples from Stations RS-18, SP-14, SP-15, HY-12, HY-17, and CI-11, which had dissolved oxygen values below 4 mg/L at termination.

Seawater controls had a mean abnormality rate of 4 percent, which is well below the 10 percent abnormal development criterion suggested by ASTM (1983) as acceptable for bivalve larvae bioassay controls. Mean mortality in the Cd-spiked seawater was 100 percent, and mean mortality in the Cd-spiked sediment was >99 percent. These results are in agreement with expected mortality rates for the spiked samples.

Mortality values generally agreed with data on abnormalities. At stations with mean abnormalities of <20 percent, mortality rates were generally low (i.e., <30 percent).

Results for Commencement Bay stations were compared with those for the reference area (Carr Inlet) using the t-test. The analysis indicated that the mean abnormalities in 15 test sediments were significantly different ($P<0.05$, experimentwise error rate) from those in the Carr Inlet samples. Sediment samples displaying significantly increased oyster larvae abnormality rates are identified in Table 3.29.

3.3.3.2 Dilution Bioassays--

Results of the oyster larvae sediment dilution bioassays are summarized in Table 3.30. Salinity, pH, and dissolved oxygen values remained at acceptable levels [as defined by ASTM (1983)] for samples from Stations HY-42, RS-18/19, and BL-25. However, dissolved oxygen levels for samples from Stations CI-11 and SP-14 were below 4 mg/L in all but the 90 percent dilutions with clean material. This depression in dissolved oxygen concentration was probably caused by the high organic content of these sediments (9 and 16 ppm TOC, respectively).

Results indicate that oyster abnormality decreases with declining concentrations of test sediments that were progessively diluted with clean control sediments. In test sediments from Stations HY-42 and BL-25, dilutions of 75-90 percent were required to reduce oyster abnormality to control levels. For samples from Stations SP-14, CI-11, and RS-18/19, dilutions greater than 90 percent were required to reduce sediment toxicity to control levels. Calculation of 48-h EC_{50} values indicated that the most toxic sediments were those from Stations RS-18/19 (EC_{50} = 9.8 g/L) and SP-14 (EC_{50} = 6.8 g/L). However, it should be noted that both of these sediments were high in organic matter, as well as being high in contaminant concentrations.

Comparison of the initial (non-dilution) bioassays on these sediments with the results of the 100 percent test sediment concentration for the dilution bioassays indicated a high level of agreement for three of five sediments: HY-41, SP-14, and RS-18/19 (Table 3.28). Sediments from Station BL-25 showed an increase in toxicity and those from Station CI-11 showed a decrease in toxicity, which may be attributable to the effects of sediment

TABLE 3.30. SUMMARY OF OYSTER LARVAE SEDIMENT DILUTION BIOASSAYS

Station Number	Test Sediment Concentration[a]	Number Surviving[b]	Relative Percent Mortality[c]		Percent Abnormality[d]	
			Mean	SD	Mean	SD
HY-42	100	49	83.0	2.2	33.8	2.8
HY-42	75	81	71.7	4.0	31.5	0
HY-42	50	48	83.2	11.4	30.8	1.7
HY-42	25	161	43.9	9.6	17.8	0.9
HY-42	10	160	44.1	13.4	1.4	2.0
BL-25	100	58	79.9	9.6	35.3	2.1
BL-25	75	46	84.1	5.2	32.7	1.8
BL-25	50	121	57.7	8.9	21.4	1.3
BL-25	25	154	46.2	23.2	21.6	5.2
BL-25	10	191	33.4	21.0	11.4	2.1
SP-14	100	0	100.0	0	--	--
SP-14	75	2	99.5	0.7	66.7	0
SP-14	50	10	96.7	1.2	84.5	1.7
SP-14	25	19	93.4	2.0	36.2	4.1
SP-14	10	51	82.3	4.2	24.0	6.9
CI-11	100	66	76.9	5.9	40.6	2.4
CI-11	75	25	91.4	2.7	41.1	1.5
CI-11	50	58	79.7	8.9	37.8	3.2
CI-11	25	72	75.0	6.2	40.0	1.0
CI-11	10	103	64.0	6.9	25.0	7.5
RS-18/19	100	25	91.3	3.0	62.3	1.3
RS-18/19	75	38	86.9	5.2	62.8	0.4
RS-18/19	50	49	82.9	3.0	50.4	4.4
RS-18/19	25	16	94.6	4.2	55.7	2.1
RS-18/19	10	123	57.0	4.5	25.0	5.4
Seawater Control	0	286	--	--	6.9	0.4
Sediment Control	0	200	30.1	5.4	8.1	1.3

[a] Percent of test sediments mixed with West Beach control sediments. The 0-percent concentration contained only control sediments.

[b] Mean of two replicates after 48-h exposure to sediments.

[c] Percent mortality relative to the mean number of surviving embryos and larvae in the seawater control.

[d] Percent of surviving embryos and larvae that had not developed to straight-hinge stage.

storage (Cummins, J., January, 1983-February, 1984, personal communication).

3.3.4 Discussion

3.3.4.1 Amphipod Bioassays--

The use of Rhepoxynius abronius to determine the acute lethality of field-collected sediments has been documented by Swartz et al. (1982a, 1985), Chapman et al. (1982a,b), and Chapman and Fink (1984). This amphipod species is a sensitive indicator of contaminated areas both by its absence from some natural populations in such areas (Swartz et al. 1982a; Comiskey et al. 1984), and by its response to contaminated sediments in laboratory studies (Swartz et al. 1985).

In the present study, exposure to sediments from 18 stations of the 52 induced statistically significant acute lethality to R. abronius as compared to a reference area (Carr Inlet). All areas tested, with the exception of Middle Waterway (one station), contained one or more sampling sites with statistically significant amphipod mortality.

During the amphipod bioassays, sediment sample SP-14 from the area of Champion International developed a white, gelatinous mass on the sediment surface. This mass was determined by microscopic examination to be inhabited by filamentous, colorless bacteria, which were probably sulfur bacteria. Their appearance on the sediment surface indicated that the sediments were anoxic through to the surface. Vigorous aeration failed to oxygenate these exposures. The amphipods more likely died from anoxia in this sample than from other causes. Low dissolved oxygen was not a problem in any other amphipod bioassay.

3.3.4.2 Oyster Larvae Bioassays--

In the present study, exposure to sediments from 15 of the 52 stations induced statistically significant oyster larvae abnormalities as compared to the reference area (Carr Inlet). Exposure to sediments from four of the eight areas in Commencement Bay tested induced significantly increased oyster larvae abnormalities: Ruston-Pt. Defiance Shoreline, St. Paul Waterway, City Waterway, Hylebos Waterway.

Water quality data taken after the 48-h bioassay period indicated that high larval mortality and high abnormality rates from exposure to sediments from 5 of the 50 tested stations were at least partly attributable to low dissolved oxygen levels (3-4 mg/L at termination): Stations SP-14, SP-15, HY-12, HY-17, and CI-11. The very low dissolved oxygen concentrations at Station RS-18 (<1 mg/L) may be responsible for the bioassay toxicity observed. All of these stations had organically enriched sediments with TOC concentrations exceeding 5 ppm.

In cases of low dissolved oxygen during bioassay exposures, it is not possible to discriminate between potential effects of lack of oxygen and toxic chemical contamination. At Station SP-14 there was evidence of stress due to low dissolved oxygen in both the amphipod and oyster larvae bioassays. However, at Stations HY-12 and HY-17 there were no statistically significant amphipod mortalities, as well as no evidence of stress due to low dissolved oxygen in the amphipod exposure. Therefore, at these sites the effects on oyster larvae may have been the result of low oxygen. At Stations SP-15 and CI-11, there were significant amphipod mortalities with no evidence of oxygen depletion. These results indicate the presence of toxic contamination that may have also caused the oyster larvae abnormalities.

3.3.4.3 Dilution Bioassays--

In both amphipod and oyster larvae sediment bioassays, dilution of selected toxic sediments with clean sediments reduced toxicity. Similar results were observed by Chapman and Fink (1984) in sediment dilution studies measuring sublethal oligochaete respiratory response to sediments from Elliott Bay. In the amphipod bioassays, a 50-75 percent dilution was generally sufficient to eliminate the toxic response. Chapman and Fink (1984) found a 50 percent dilution was sufficient to eliminate the toxic response in oligochaete respiration bioassays. However, in the oyster larvae bioassays, dilutions of 70-90 percent or greater were required to eliminate the toxic response. This difference is not surprising, since the oyster larvae bioassay is more sensitive than the amphipod or oligochaete respiration bioassay (Chapman et al. 1984).

3.3.4.4 Comparison of Bioassays--

A comparative summary of sediment toxicity as determined by the amphipod and oyster larvae bioassays is presented in Figures 3.45-3.47. Sediments from 24 of the 52 stations tested were toxic in at least one of these two tests. Similar results were obtained for 10 stations by both methods, and approximately equal numbers of samples were toxic by only one method (amphipod bioassay-seven samples; oyster larvae bioassay-six samples). The level of agreement for the presence of toxic effects (10 of 23 tests or 43 percent) between the two tests is considered to be high, considering the two kinds of response (i.e., lethal and sublethal) and the two life-stages (i.e., adult organism and fertilized egg). As noted by Chapman and Long (1983), different bioassay organisms and tests will respond differently to the same sediment sample, reflecting both their own uniqueness and that of the sample.

The relationship between amphipod mortality and oyster larvae abnormality for individual sampling stations is shown in Figure 3.48. Nonparametric statistical comparisons using Spearman's rank correlation coefficient indicate a highly significant degree of agreement between the two bioassay responses ($P<0.0001$). This close association of results is also indicated by a coefficient of determination (R^2) of 0.725. The slope of the regression relationship was 1.02, indicating an almost equal agreement between the magnitudes of the two responses.

3.3.5 Comparison with Historical Data

Previous *R. abronius* sediment bioassay tests in Commencement Bay have been conducted by Swartz et al. (1982a), who tested 175 sediment samples, 129 of which were from Commencement Bay waterways. The remaining samples were from the outer bay. Two samples from the Ruston-Pt. Defiance Shoreline were from different areas than those sampled in the present study. Data

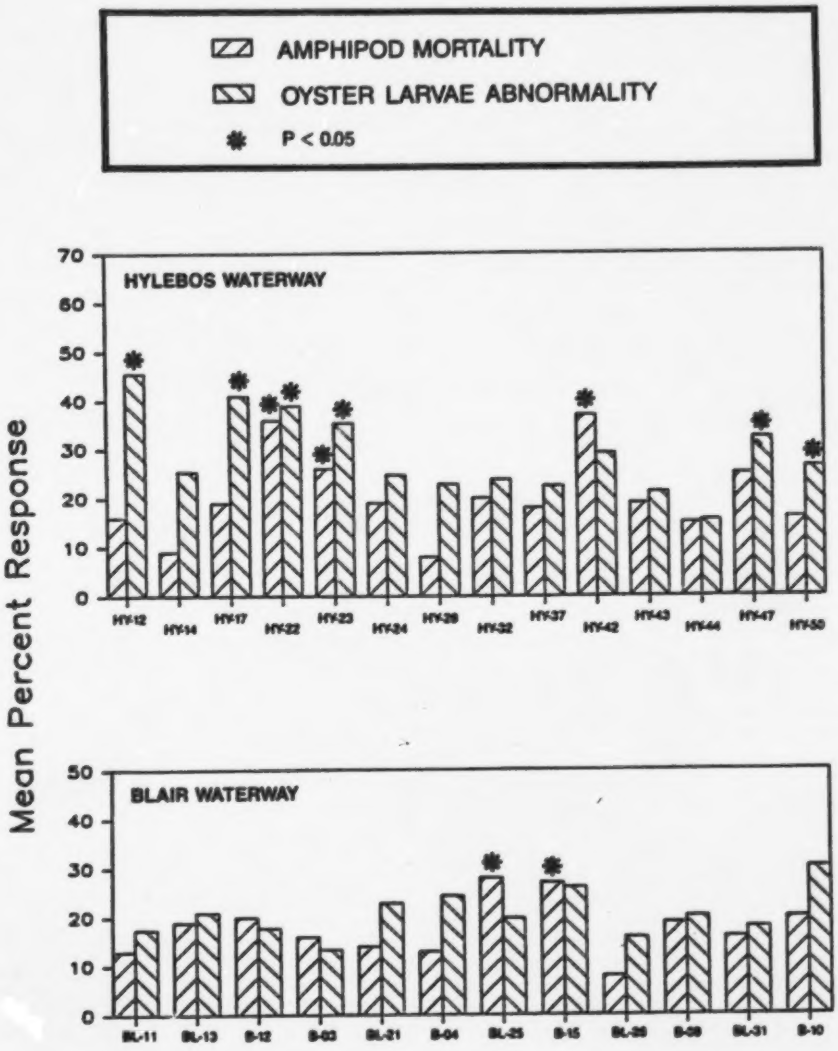


Figure 3.45. Bioassay responses to sediments from Hylebos and Blair Waterways.

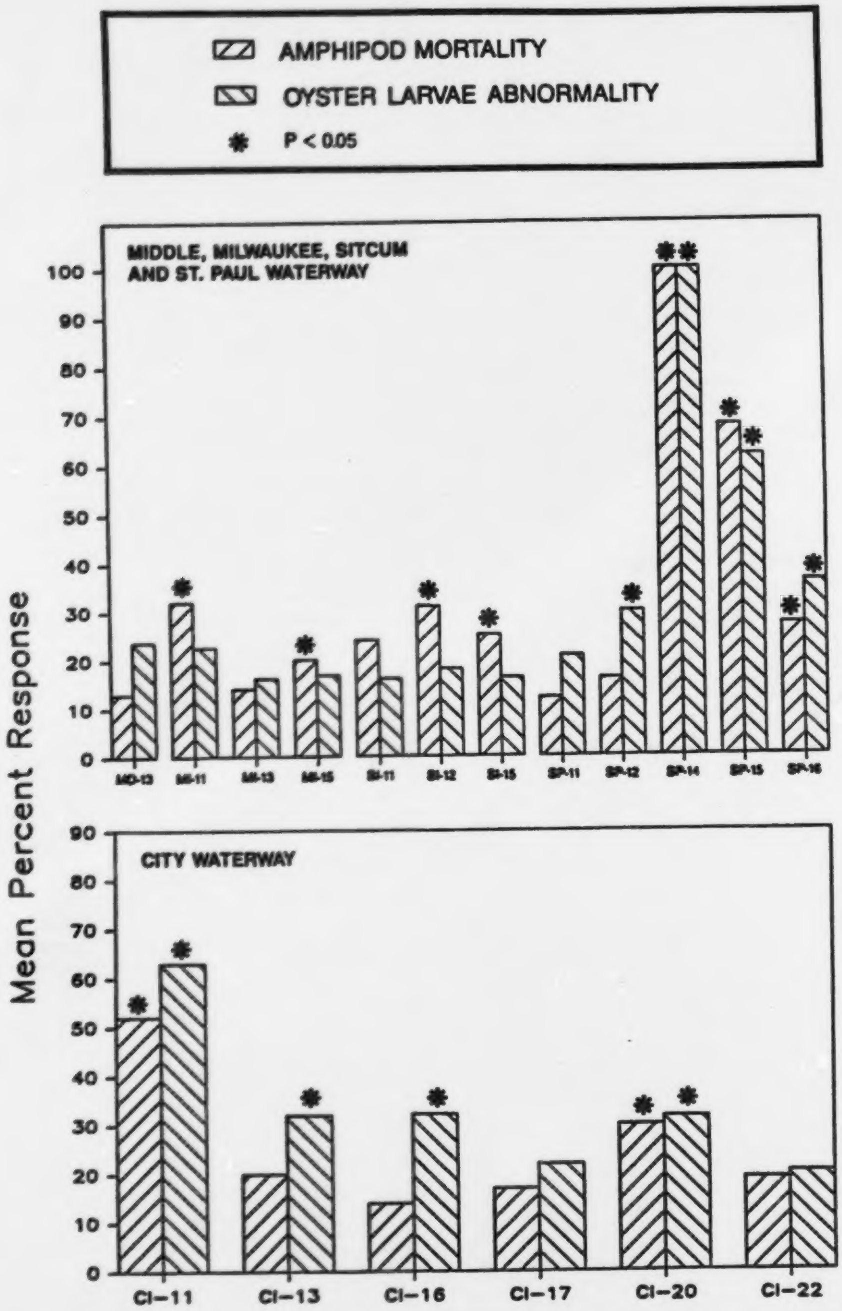


Figure 3.46. Bioassay responses to sediments from Middle, Milwaukee, Sitcum, St. Paul, and City Waterways.

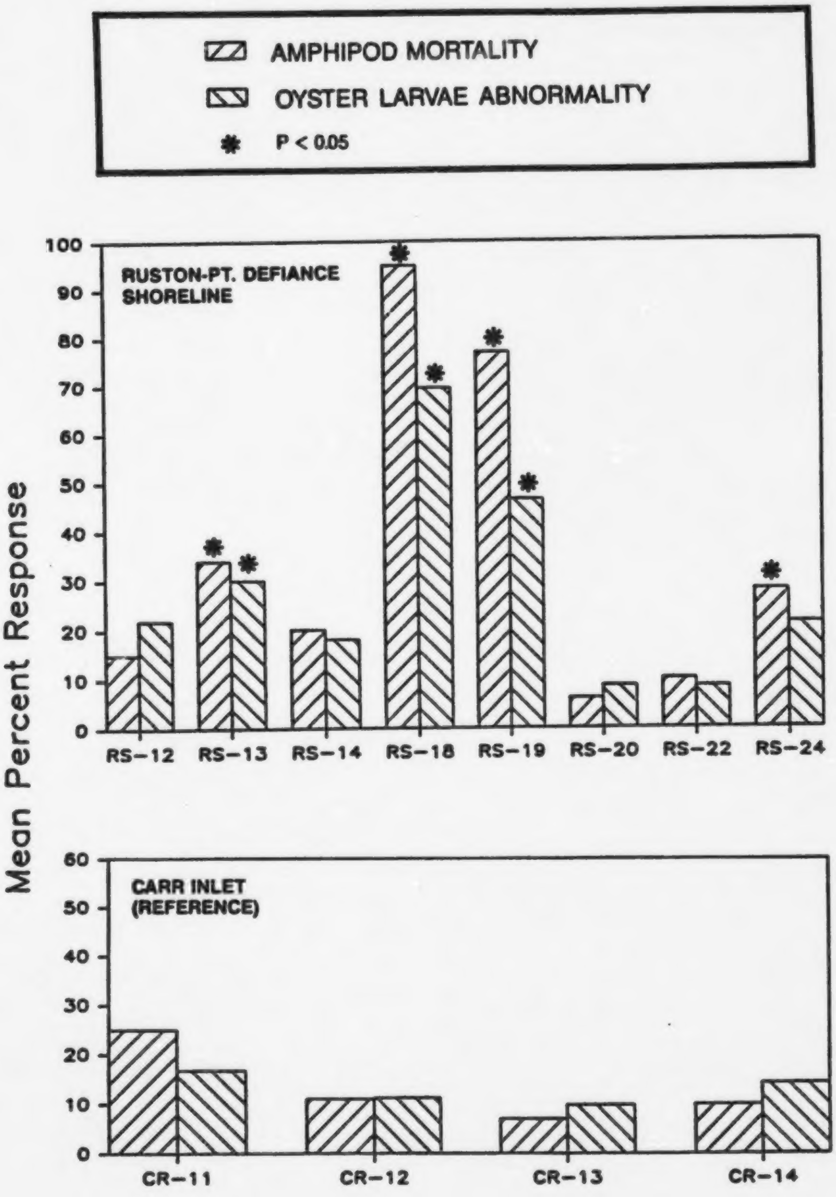


Figure 3.47. Bioassay responses to sediments from Ruston-Pt. Defiance Shoreline and Carr Inlet.

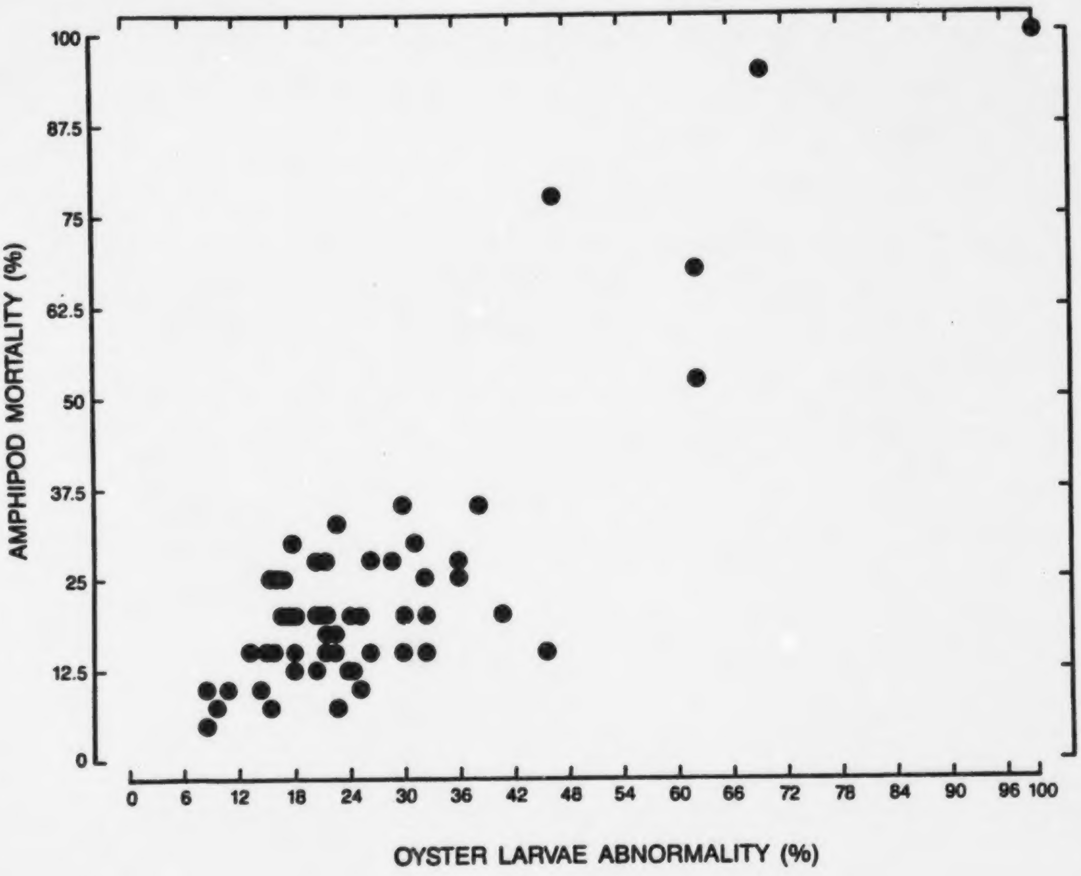


Figure 3.48. Relationship between amphipod and oyster larvae bioassay results.

for 125 of the 129 waterway stations represent unreplicated samples. Of the 129 waterway samples, the results for 78 (60 percent) exceeded the highest possible control mortality, while 101 samples (78 percent) were above the level detected by ANOVA to be statistically significant for representative samples (Swartz, R., January 9-February 3, 1984, personal communication). By contrast, in the present study only 15 of 44 samples from the waterways (34 percent) were significantly lethal by this test.

There are three primary reasons for the apparent differences between the present study and previous work by Swartz et al. (1982a). First, the use of replicated samples in the present study enabled more rigorous, statistical determinations of lethality. Second, some of Swartz et al.'s (1982a) samples were nearshore, whereas the present study collected all samples from offshore areas. For instance, Swartz et al. (1982a) found that nearshore/intertidal sediments near the Lincoln Avenue drain in Blair Waterway were relatively lethal, whereas in the present study sediment tested from this area was only collected from mid-channel (Station BL-21), and this material was determined to be nonlethal to the amphipods. Third, there was a 3-yr time period between the two studies, during which time sediment toxicity may have declined.

In some areas of overlap between the present study and that of Swartz et. al. (1982a) (e.g., Stations HY-22, HY-23, HY-25, SI-15, SP-14, and CI-11), sediments found to be particularly lethal by Swartz et al. (1982a) were also significantly lethal in the present study. There are also areas of overlap where relatively high mortalities were recorded by Swartz et al. (1982a), while testing with amphipods in the present study indicated no significant lethality. These areas include Stations HY-17, HY-32, and CI-16. It is possible that sediment toxicity in these areas has been reduced due to dredging, sedimentation, cessation of contaminant inputs, or other causes. However, it is also possible that these differences between the two studies are simply a function of the patchy distribution of sediment toxicity in the waterways (Swartz et al. 1982a). Results of the replicate tests conducted in the present study should be considered representative of present conditions at the stations tested.

Oyster larvae sediment bioassay tests in Commencement Bay have also been conducted by Chapman et al. (1983) and Pierson et al. (1983). The latter investigators tested nine stations in Blair and Sitcum Waterways using different techniques than in the present study. Unacceptably high control abnormalities (range of means was 12.4 to 100 percent) negate the usefulness of these data, and this study is not further considered herein.

Chapman et al. (1983) tested nine stations using the oyster larvae bioassay in Commencement Bay waterways, including Hylebos, Blair, Sitcum, and City Waterways. Results were compared using subjective, rather than statistical, criteria. Exposure to sediments from seven of these nine stations (78 percent) resulted in high toxicity compared to controls based on >20 percent mean abnormalities. Mean control abnormalities were <2 percent. In the present study, 16 of 44 stations (36 percent) were significantly toxic based on oyster larvae abnormalities. As was the case with the amphipod tests, there was an apparent decrease in overall toxicity in the present study compared to previous testing. Seven of the nine stations tested by Chapman et al. (1983) overlapped with stations in the present study. Results from five of these were similar in both studies (Stations HY-14, HY-23, HY-47, SI-15, CI-22). Sediments from two of the nine common stations (Stations BL-21, CI-17) showed relatively high toxicity in previous studies but no significant toxicity in the present study. Whether there has been a reduction in sediment toxicity between Chapman et al.'s (1983) sampling in August, 1982 and the present sampling in March, 1984 cannot be determined based on comparisons between only nine samples.

3.3.6 Summary

- Sediments from 24 of the 52 Commencement Bay sites tested had statistically significant toxicities for one or both of the bioassays when compared with the Carr Inlet reference area (Figure 3.49).
- Ten of the sites were toxic in both bioassays. These sites were located in Hylebos Waterway, City Waterway, St. Paul Waterway, and on the Ruston-Pt. Defiance Shoreline.
- Overall, there was good agreement between the two bioassays, especially as the toxic response exceeded 50 percent.
- Dilution bioassays indicated that in some areas (e.g., Stations SP-14, RS-18/19, CI-11) the sediments were so toxic that a 90 percent dilution was not sufficient to reduce toxicities to reference levels.
- Oyster larvae abnormalities at some of these highly toxic sites may have been due in part to low dissolved oxygen resulting from high organic content of the sediments. The amphipod mortalities at Station SP-14 may have also resulted from low dissolved oxygen.

3.4 FISH ECOLOGY

3.4.1 Introduction

This section provides a description of general characteristics of the total demersal fish assemblages and the English sole populations sampled at 17 trawl transects in Commencement Bay and Carr Inlet (see Section 2.6). The total assemblages in Commencement Bay and Carr Inlet are compared with respect to species composition, species number, species diversity, and total abundance. English sole populations in Commencement Bay and Carr Inlet are compared with respect to median length, abundance, sex ratio, and condition. Finally, results of the present study are compared with historical data collected in Commencement Bay.

3.4.2 Total Fish Assemblages

3.4.2.1 Species Composition--

A total of 6,686 fishes, representing 17 families and 40 species, was sampled in this study (Table 3.31). Commencement Bay study areas yielded 4,951 individuals and 38 species, whereas 1,735 fishes and 13 species were

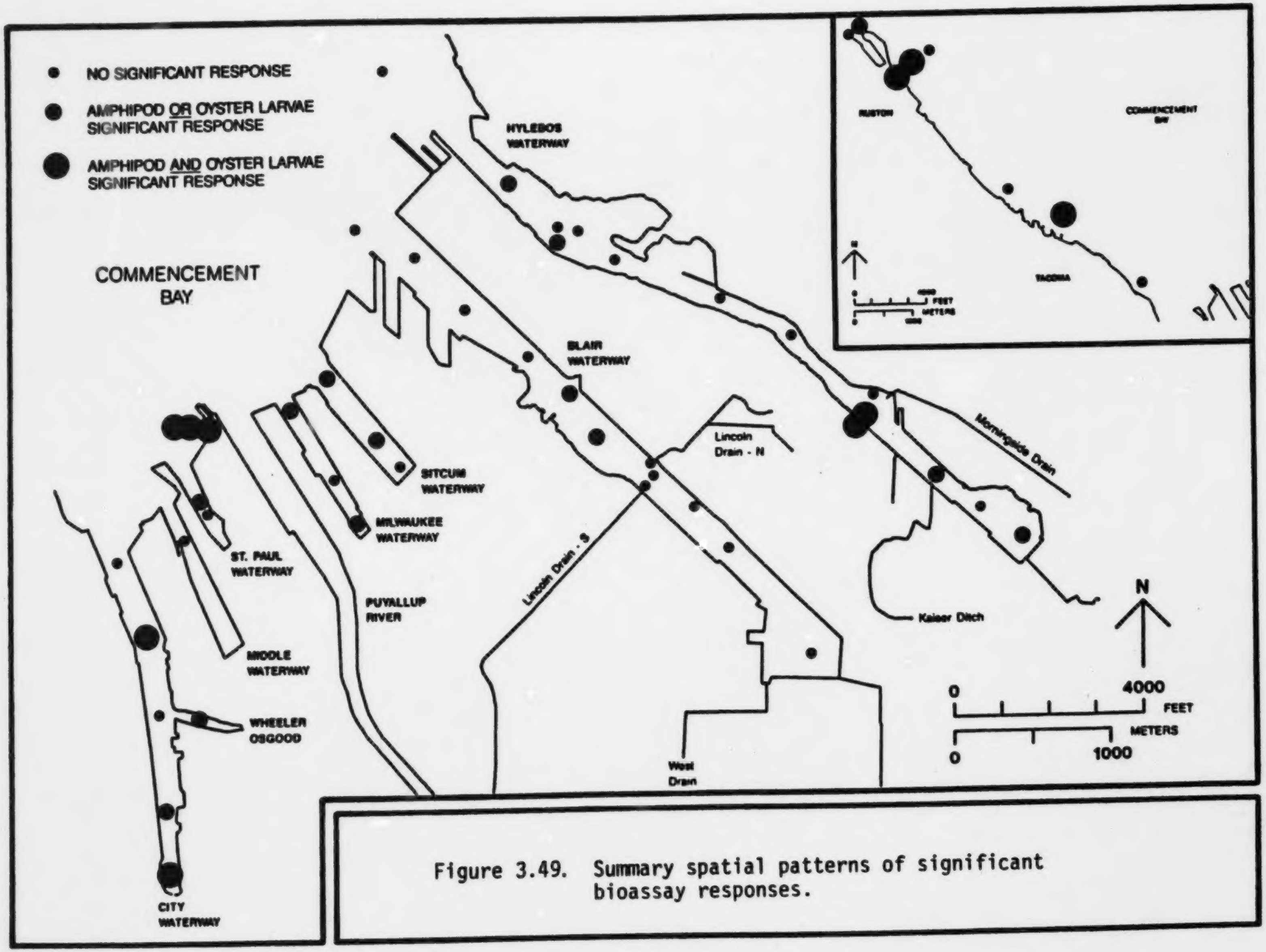

NO SIGNIFICANT RESPONSE
AMPHIPOD OR OYSTER LARVAE SIGNIFICANT RESPONSE
AMPHIPOD AND OYSTER LARVAE SIGNIFICANT RESPONSE
COMMENCEMENT BAY
HYLEBOS WATERWAY
BLAIR WATERWAY
SITCUM WATERWAY
MILWAUKEE WATERWAY
ST. PAUL WATERWAY
PUYALLUP RIVER
MIDDLE WATERWAY
WHEELER OSGOOD
CITY WATERWAY
Lincoln Drain - N
Lincoln Drain - S
Morningside Drain
Kaiser Ditch
West Drain
N
0
4000
FEET
METERS
0
1000
RUSTON
COMMENCEMENT BAY
TACOMA
N
FEET
METERS

Figure 3.49. Summary spatial patterns of significant bioassay responses.

TABLE 3.31. RELATIVE ABUNDANCES OF FISHES CAPTURED IN COMMENCEMENT BAY AND CARR INLET

Family	Species	Common Name	Relative Abundance (%)	
			Commencement Bay	Carr Inlet
Squalidae	*Squalus acanthias*	spiny dogfish	0.1	
Rajidae	*Raja rhina*	longnose skate		0.1
Chimaeridae	*Hydrolagus colliei*	spotted ratfish	2.3	
Clupeidae	*Clupea harengus pallasi*	Pacific herring	2.1	
Engraulidae	*Engraulis mordax mordax*	northern anchovy	[a]	
Batrachoididae	*Porichthys notatus*	plainfin midshipman	0.1	
Gadidae	*Gadus macrocephalus*	Pacific cod	[a]	
	Merluccius productus	Pacific hake	0.1	
	Microgadus proximus	Pacific tomcod	4.3	
Zoarcidae	*Lycodopsis pacifica*	blackbelly eelpout	1.5	
Embiotocidae	*Cymatogaster aggregata*	shiner perch	0.6	
	Embiotoca lateralis	striped seaperch	0.1	
	Rhacochilus vacca	pile perch	0.1	
Bathymasteridae	*Ronquilus jordani*	northern ronquil	0.3	
Stichaeidae	*Lumpenus sagitta*	snake prickleback	0.3	0.2
Scorpaenidae	*Sebastes auriculatus*	brown rockfish	0.1	
	Sebastes caurinus	copper rockfish	[a]	
	Sebastes maliger	quillback rockfish	0.6	
	Sebastes melanops	black rockfish	[a]	
Hexagrammidae	*Hexagrammos stelleri*	whitespotted greenling	0.2	
	Ophiodon elongatus	lingcod	0.1	
Cottidae	*Chitonotus pugetensis*	roughback sculpin	0.6	5.6
	Enophrys bison	buffalo sculpin	0.1	
	Leptocottus armatus	Pacific staghorn sculpin	1.1	0.3
	Scorpaenichthys marmoratus	cabezon	[a]	
Agonidae	*Agonopsis emmelane*	northern spearnose poacher		0.1
	Agonus acipenserinus	sturgeon poacher	[a]	0.2
Bothidae	*Citharichthys sordidus*	Pacific sanddab	2.7	
	Citharichthys stigmaeus	speckled sanddab	0.4	1.7
Pleuronectidae	*Eopsetta jordani*	petrale sole	[a]	
	Glyptocephalus zachirus	rex sole	[a]	
	Hippoglossoides elassodon	flathead sole	3.9	
	Inopsetta ischyra	hybrid sole	[a]	
	Lepidopsetta bilineata	rock sole	13.8	25.0
	Lyopsetta exilis	slender sole	0.2	0.4
	Microstomus pacificus	Dover sole	7.6	
	Parophrys vetulus	English sole	55.6	65.8
	Platichthys stellatus	Starry flounder	0.4	0.3
	Pleuronichthys coenosus	C-O sole	0.1	0.2
	Psettichthys melanostictus	sand sole	0.4	0.1
		TOTAL CATCH	4,951	1,735

[a] <0.1 percent.

captured in Carr Inlet. Much of this discrepancy in catches resulted primarily from the larger sampling effort expended in Commencement Bay (15 transects) compared to Carr Inlet (2 transects), but may also have been partly due to increased habitat complexity (e.g., pilings, rocks, debris) in Commencement Bay.

The fish assemblages sampled in both Commencement Bay and Carr Inlet were dominated by pleuronectids (82.0 and 91.8 percent, respectively). The most abundant pleuronectids were English sole (55.6 and 65.8 percent, respectively) and rock sole (13.8 and 25.0 percent, respectively).

3.4.2.2 Assemblage Characteristics--

Individual study areas within Commencement Bay were compared qualitatively with the Carr Inlet reference area on the basis of three major characteristics of fish assemblages: total abundance, total number of species, and species diversity (Figure 3.50). The latter parameter was represented by the Shannon-Wiener Index (H'; Shannon and Weaver 1949). For study areas including more than one trawl transect (Hylebos, Blair, and City Waterways; Ruston-Pt. Defiance Shoreline; and Carr Inlet), the mean value of all transects within each area was considered for each assemblage characteristic.

For six of the eight Commencement Bay study areas, total abundance of fish assemblages was over twice as large as that in Carr Inlet (60 fishes/100 m). Only Hylebos Waterway and Ruston-Pt. Defiance Shoreline had abundances similar to that in Carr Inlet. Total numbers of species in all Commencement Bay study areas (range of 10.0 to 14.5) were relatively similar to that in Carr Inlet (10.5). Diversity indices of fish assemblages in all Commencement Bay study areas were greater than that in Carr Inlet (0.96). Diversity indices in four of the eight study areas (Hylebos, Milwaukee, and City Waterways, and the Ruston-Pt. Defiance Shoreline) exceeded that in Carr Inlet by a factor of 1.5 or more.

In summary, fish assemblages in Commencement Bay study areas generally were more abundant and more diverse than those in Carr Inlet. Total numbers of species were similar among all areas. Although these comparisons are largely descriptive, they show no indication that the gross characteristics of fish assemblages in Commencement Bay were negatively affected by chemical contamination. The relatively high abundances of demersal fishes in the Commencement Bay waterways may be a result of high abundances of benthic macroinvertebrates in the area. English sole have been shown to prefer cirratulid polychaetes and molluscs as prey items (Becker 1984). Abundances of both of these invertebrate groups are enhanced in Commencement Bay relative to Carr Inlet, thus providing a rich food supply for bottom-feeding fishes.

3.4.3 English Sole Populations

3.4.3.1 Length Distribution--

As shown in Section 3.4.2.1 English sole was the most abundant species in both Commencement Bay and Carr Inlet, accounting for 55.6 and 65.8 percent (respectively) of overall assemblages. Although relative abundances of English sole were similar between the two embayments, length distributions of captured fish (Figure 3.51) were significantly different ($P<0.001$,

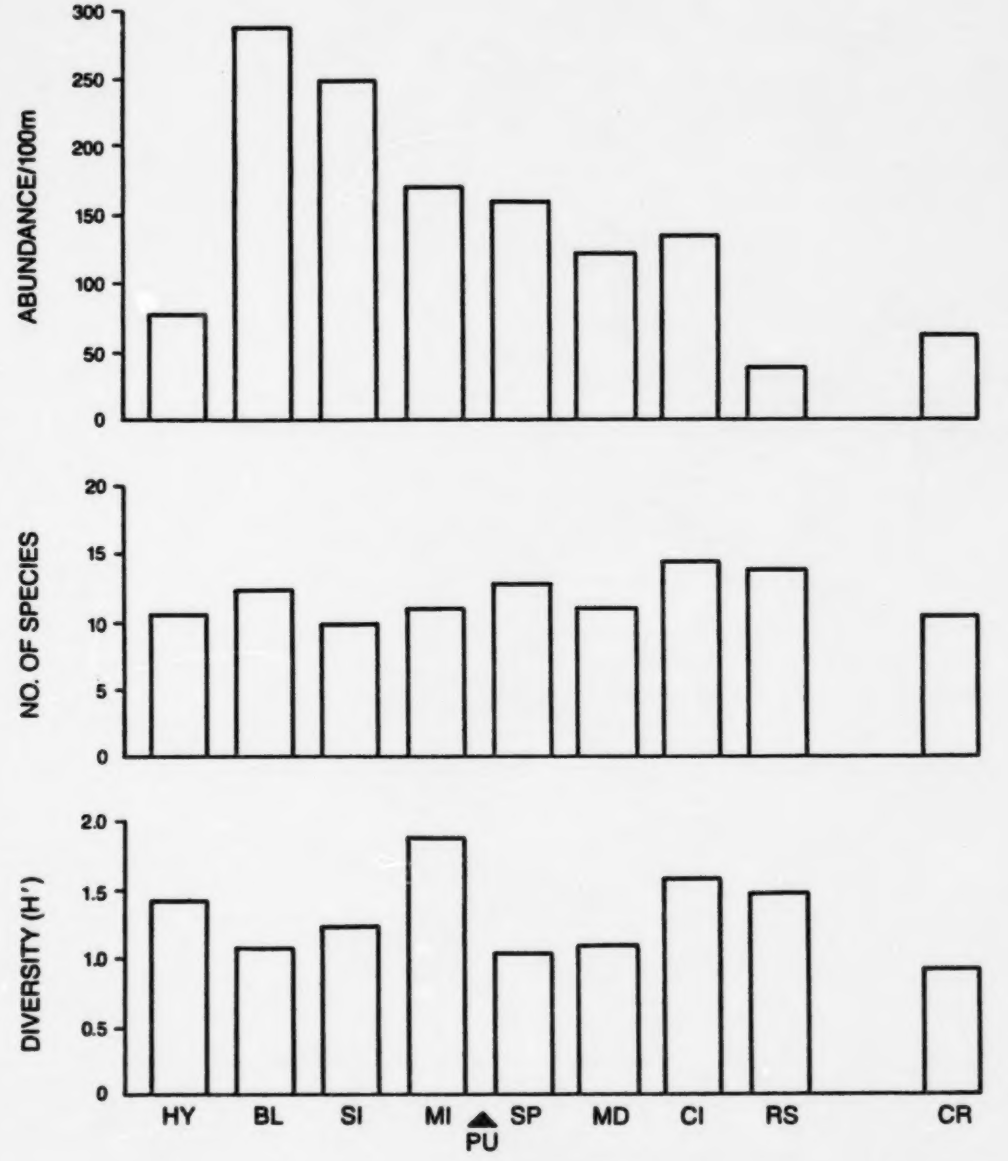


Figure 3.50. Comparisons of major characteristics of fish assemblages from Commencement Bay study areas with those of the assemblage from Carr Inlet.

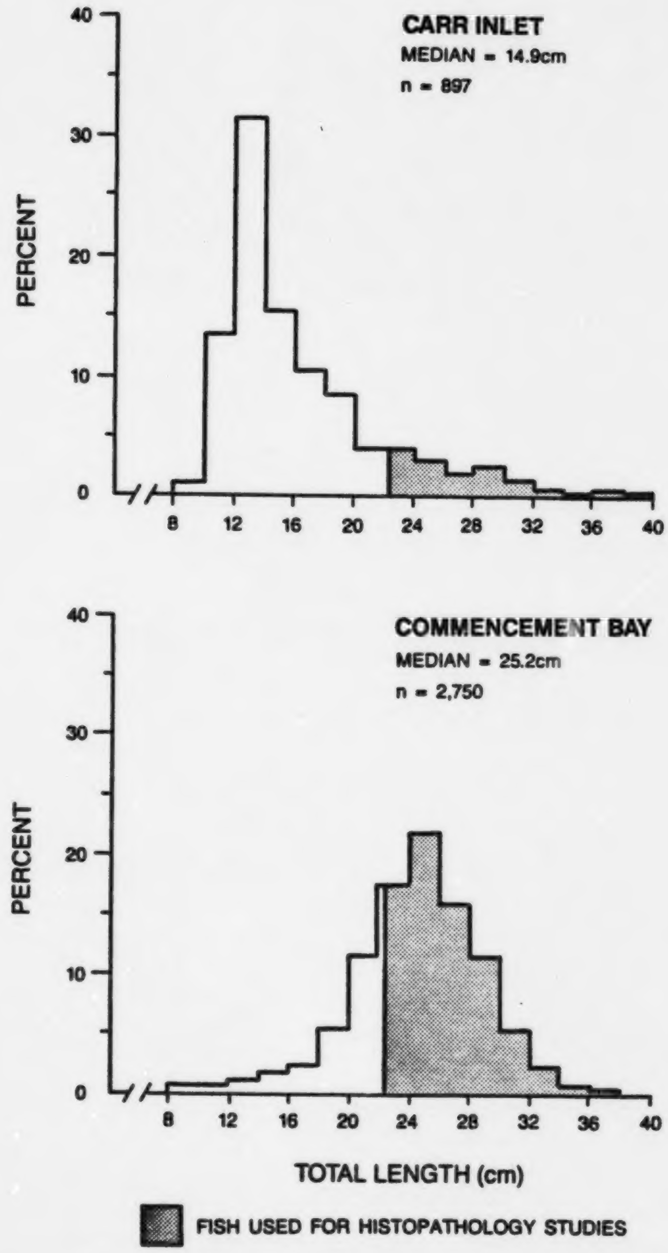


Figure 3.51. Length frequency distributions of English sole captured in Carr Inlet and Commencement Bay.

Mann-Whitney U-test). Median length in Carr Inlet (14.9 cm) was substantially lower than that in Commencement Bay (25.2 cm) because populations in the former embayment were dominated by young fish. For example, fish smaller than 20 cm accounted for over 80 percent of the population in Carr Inlet, but only 4 percent of the population in Commencement Bay. This size discrepancy probably arises from the fact that juvenile English sole prefer shallow sandy habitats as nursery areas (Ketchen 1956). Thus, the muddy nature and altered benthos of most areas sampled in Commencement Bay may be suitable for adult English sole, but largely unacceptable for younger individuals.

The large differences in median length of English sole between Commencement Bay and Carr Inlet underline the value of setting a minimum size (i.e., an index of age) limit for histopathological analysis. For instance, if fish had been selected randomly for this analysis, most individuals subsampled from Carr Inlet would likely be smaller (and thus younger) than those taken from Commencement Bay. Because several liver disorders in English sole are functions of age (e.g., Malins et al. 1982; McCain et al. 1982; Section 3.5.5 of this study), comparisons of prevalences of these conditions between embayments would be strongly biased by the different age distributions of the subsampled fish.

3.4.3.2 Abundance--

At five of the eight Commencement Bay study areas (Blair, Sitcum, St. Paul, Middle, and City Waterways), English sole abundance was more than twice that in Carr Inlet (mean of 28.9 fish/100 m) (Figure 3.52). The Ruston-Pt. Defiance Shoreline was the only study area in which English sole abundance was lower than that in Carr Inlet. The trawl transect having the greatest abundance of this species in both embayments (498.3 fish/100 m) was BL70, at the mouth of Blair Waterway. The lowest abundance in the study (2.3 fish/100 m) occurred at Transect RS72, off Pt. Defiance. These data indicate that, except for the Ruston-Pt. Defiance Shoreline, the Commencement Bay study areas generally attracted considerably more English sole than did the reference area. A possible explanation for this pattern is that most of the Commencement Bay study areas support considerably higher standing crops of English sole prey (i.e., benthic invertebrates) than does Carr Inlet (see Section 3.2).

3.4.3.3 Sex Ratio--

As noted previously (Section 2.6), sex was examined in all 1,020 English sole subsampled for histopathological analysis. However, sex could not be distinguished for 13 individuals (8, 3, 1, and 1 from Trawl Transects CI72, CI71, MD70, and RS70, respectively). To determine whether sex ratios varied with the physical characteristics of sediments at each study area, the male percentages of English sole populations were compared with the fine-grained (i.e., silt and clay) fraction of sediments at all study areas using Spearman's rank correlation coefficient (r_s).

Male percentages were significantly correlated ($P<0.05$) with percent fine-grained sediments in a positive direction (Figure 3.53). Percentages ranged from 20.8 at Carr Inlet (12.2 percent fine-grained sediments) to 98.3 in Sitcum Waterway (78.8 percent fine-grained sediments). This same pattern was found by Becker (unpublished) for English sole (>150 mm TL)

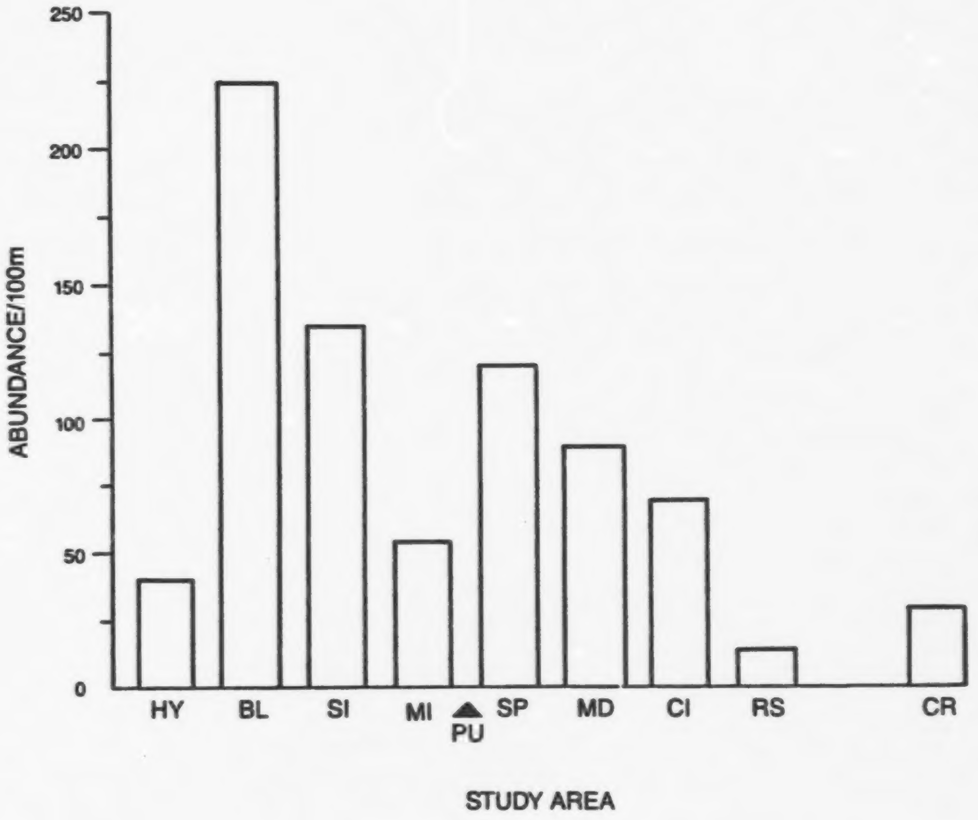


Figure 3.52. Comparison of abundances of English sole from Commencement Bay study areas with the abundance from Carr Inlet.

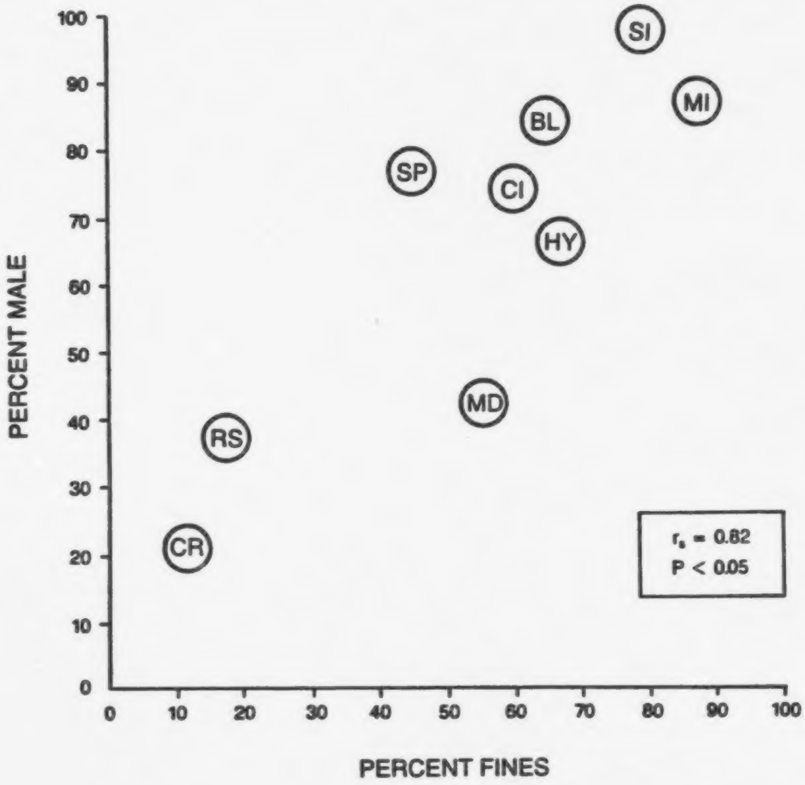


Figure 3.53. Comparison of male percentages of English sole populations with fine-grained sediment fractions (silt plus clay) using the Spearman rank correlation coefficient (r_s).

collected at 12 sites in Commencement Bay, Elliott Bay, and Sinclair Inlet in 1981 ($r_s=0.73$, $P<0.05$). Although the reason for this stratification by sex is unknown, it is clear that possible sex-related differences in prevalences of liver conditions must be examined before study areas can be compared. This potential bias is considered in Section 3.5.4.

3.4.3.4 Fish Condition--

The condition of all 1,007 English sole of known sex subsampled for histopathological analysis was compared between Commencement Bay and Carr Inlet using regression analysis. Weight-at-length (WAL) was used as the condition index (Royce 1972). This is a gross indicator of how well fish are storing energy for subsequent reproduction. Lowered WAL values may result if fish cannot find adequate food sources or if individuals are stressed or diseased. Variations in WAL as a result of gonadal development were minimal in this study because fish were sampled shortly after spawning. Comparisons of WAL were stratified by sex because WAL of females is generally larger than that of males for adult English sole (Holland 1969; Becker 1984).

To compare WAL values between embayments, weight and length of each fish was log-transformed and a least-squares linear regression line was calculated (cf. Ricker 1975). Regression lines (Figure 3.54) from both embayments were tested for coincidence using the Z-test (Kleinbaum and Kupper 1978).

The slopes of the regression lines for males were not significantly different ($P>0.05$). However, these lines were not coincident because the y-intercepts were significantly different ($P<0.05$). Thus, although the weight-lenth trend was the same in both embayments, males in Commencement Bay were heavier than males in Carr Inlet for all sizes considered.

The regression lines for females were not coincident because the slopes different significantly ($P<0.05$). Females therefore exhibited different weight-length trends in the two embayments. The regression lines intersected at a length of 32.4 cm, with fish smaller than this size (80.8 percent of the sampled fish) being heavier in Commencement Bay than in Carr Inlet.

Results of the WAL comparisons suggest that, in general, English sole from Commencement Bay were able to obtain and store more energy than conspecifics from Carr Inlet. This pattern may be a function of the higher standing crop of benthic invertebrates in Commencement Bay compared to Carr Inlet (Section 3.2). In any case, there is no evidence that chemical contamination in Commencement Bay is substantially affecting WAL of the majority of resident English sole.

3.4.3.5 Comparisons with Historical Studies--

To examine the temporal stability of sizes and male percentages of Commencement Bay English sole populations, results from Trawl Transects CI72 (mouth of City Waterway) and SI70 (Sitcum Waterway) were compared with those found by Becker (unpublished) in 1981 using similar methods, sampling times (including time of year and time of day), and station locations. Comparisons were limited to these two areas because they were the only

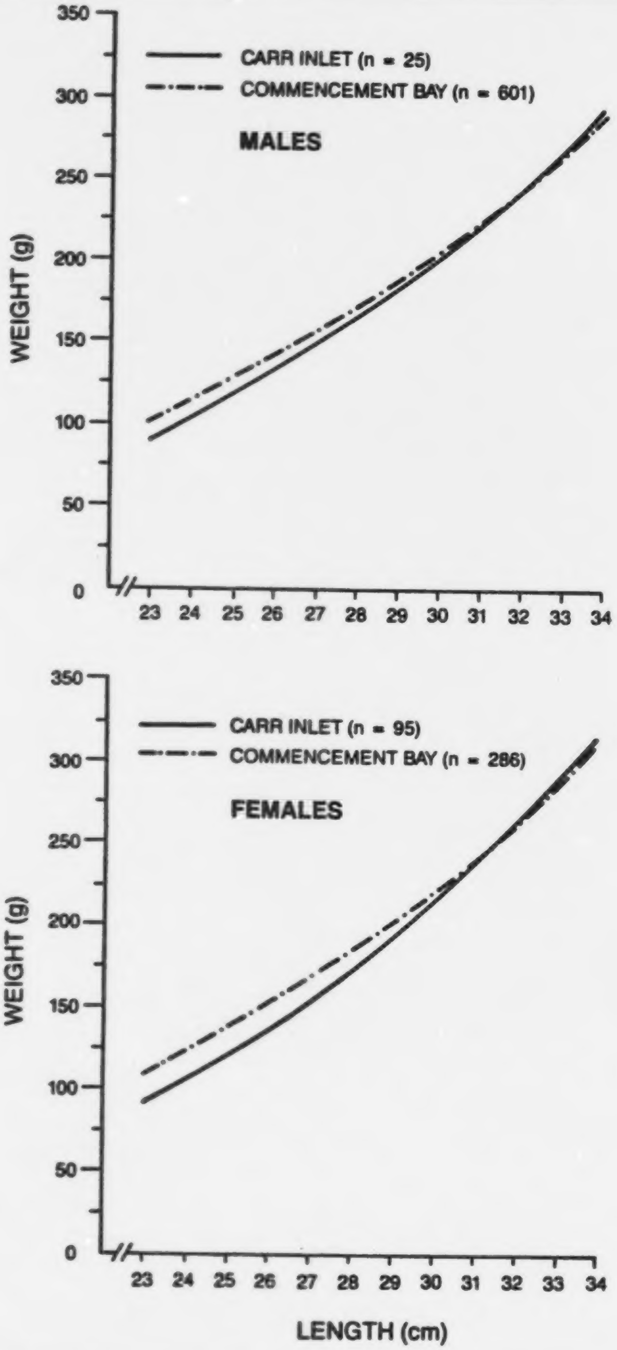


Figure 3.54. Comparisons of weight-length relationships of male and female English sole captured in Commencement Bay and Carr Inlet.

ones common to both studies. Sizes of English sole from the present study were based on all fish collected, whereas male percentages were based only on those subsampled for histopathological analysis.

Size distributions at both stations did not differ significantly ($P>0.05$, Mann-Whitney U-test) between the two studies (Figure 3.55). In both cases, the difference in median length between studies was less than 1 cm. As with median length, male percentages did not differ significantly ($P>0.05$, 2x2 contingency test) between studies at both stations. Male percentages in 1981 and 1984 were 81.4 and 73.1 (respectively) in City Waterway, and 95.7 and 98.3 (respectively) in Sitcum Waterway.

The observed similarities of median sizes and male percentages between 1981 and 1984 suggest that, although most adult English sole migrate seasonally (Ketchen 1956), the same population may utilize the Commencement Bay waterways each year. If this supposition is correct, it would imply that these fish could be exposed to waterway contaminants for a number of years, and thereby be susceptible to the negative consequences that may result from long-term contact with chemical contaminants.

3.4.4 Summary

- English sole dominated the demersal fish assemblage in both Commencement Bay and Carr Inlet, accounting for 55.6 and 65.8 percent (respectively) of each assemblage.

- Demersal fish assemblages at the eight Commencement Bay study areas generally were more abundant and more diverse than the assemblage in Carr Inlet. By contrast, total number of species was similar among all areas sampled.

- English sole sampled in Commencement Bay were significantly larger ($P<0.05$) than conspecifics collected in Carr Inlet.

- Abundance of English sole at five of the eight Commencement Bay study areas exceeded the abundance in Carr Inlet by a factor of two or more. The Ruston-Pt. Defiance Shoreline was the only study area having a lower abundance than Carr Inlet.

- The male-to-female ratio of English sole populations correlated significantly ($P<0.05$) with percent fine-grained sediment.

- Condition (i.e., weight-at-length) of all male and most female English sole was greater in Commencement Bay than in Carr Inlet.

- Length and sex ratio of English sole in City and Sitcum Waterways did not differ significantly ($P<0.05$) between the present study and historical data collected 3 yr earlier.

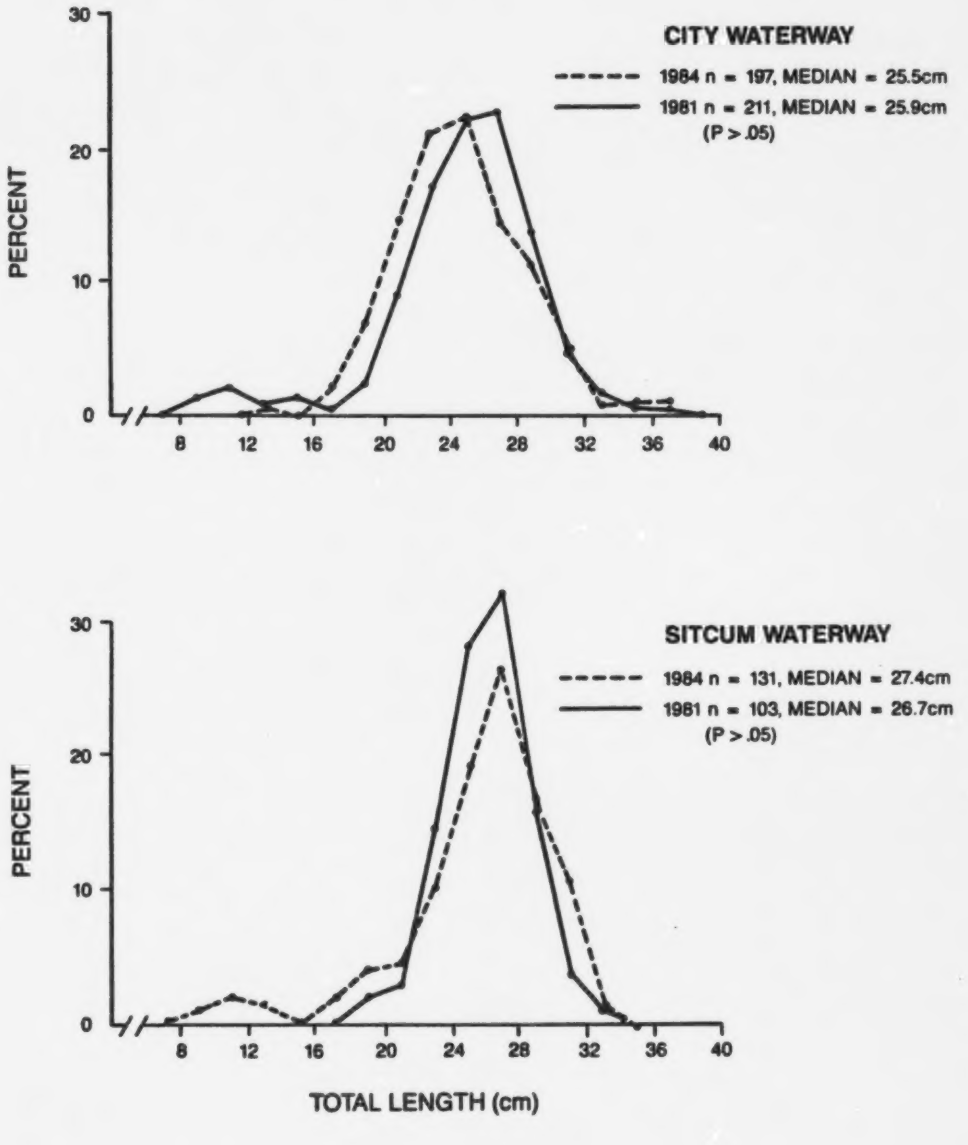


Figure 3.55. Comparisons of length distributions of English sole captured in City and Sitcum Waterways during 1981 and 1984 using the Mann-Whitney U-test.

3.5 FISH HISTOPATHOLOGY

3.5.1 Introduction

This section presents the results of histopathological analyses conducted on the livers of the 1,020 English sole subsampled at 17 trawl transects in Commencement Bay and Carr Inlet (see Figure 2.6 in Section 2.1). Grossly visible external abnormalities found on the subsampled fish are described first. The kinds of liver lesions considered in this study are described next. The relationships of these lesions to sex and age of the fish are then determined so that, if necessary, these potential confounding factors can be removed before lesion prevalences in Commencement Bay are compared with those in Carr Inlet. Lesion prevalences based on Commencement Bay as a whole, the eight study areas within the bay, and the individual trawl transects within the larger study areas are then compared statistically with prevalences in Carr Inlet. Finally, results of the present study are compared with historical data collected in Commencement Bay.

3.5.2 External Abnormalities

Although this study focused on microscopic pathological conditions of the liver, grossly visible external abnormalities of the 1,020 English sole subsampled for histopathological analysis were also recorded. The two most common external abnormalities in English sole found in Puget Sound in the past and suspected of resulting from chemical contamination are skin tumors (i.e., angioepithelial nodules, angioepithelial polyps, and epidermal papillomas) and fin erosion. None of the 1,020 subsampled English sole was affected by skin tumors, and only 9 individuals (0.9 percent) showed confirmed cases of fin erosion. Thus, the fish subsampled in the present study were relatively unaffected by these two kinds of external abnormalities.

3.5.3 Classification of Liver Conditions

Over 50 types of gross and microscopic pathological conditions were observed in the livers of the 1,020 English sole examined. These conditions ranged from common parasitic infections to clearly identifiable neoplasms. This study emphasized four lesion categories of unknown etiology (i.e., hepatic neoplasms, preneoplastic nodules, megalocytic hepatosis, and nuclear pleomorphism). The causes of these disorders are unknown. It is possible that they are induced by chemical contaminants in the environment. Moreover, morphologically similar lesions have been induced in laboratory mammals and fishes by exposure to toxic and/or carcinogenic chemicals (Malins et al. 1984). Each of the four lesion categories is described in the following sections.

3.5.3.1 Hepatic Neoplasms--

Several kinds of neoplasm have been described in English sole. Each one is discussed separately.

Liver Cell Adenoma--Liver cell adenomata are well-differentiated nodules of normal architectural appearance that generally measure more than 1.0 mm in diameter and that compress, but do not invade, the surrounding tissue.

The margin of the adenoma is distinct from the normal surrounding tissue and the tumor may be recognized by an absence of melanin macrophage centers (MMCs) or other hepatic elements (e.g., pancreas). These hypercellular foci contain hepatocytes with reduced or absent polarity, as well as reduced or absent iron pigment. The cells are monomorphic with enlarged nuclei and have variable staining patterns, ranging from basophilic to eosinophilic or vacuolated. Sometimes multiple adenomata with different characteristics may be seen within a single liver.

Hepatocellular Carcinoma--Hepatocellular carcinomata are tumors characterized by the presence of disorganized muralia and irregular borders. They grow by expansion and by invasion into surrounding hepatic parenchyma. The cells that constitute the tumor are pleomorphic, slightly hypertrophic hepatocytes that lack cellular polarity. The cells are frequently anaplastic and evidence an increased nuclear:cytoplasmic ratio. Their staining patterns vary from primarily basophilic to occasionally eosinophilic or vacuolated. The cells most often are arranged in a trabecular pattern, but occasionally may assume a pseudotubular or solid pattern. The nodules are most often devoid of MMCs or other hepatic tissue elements.

Cholangiocellular Carcinoma--Cholangiocellular carcinomata arise from bile duct epithelium. They are invasive, often poorly differentiated neoplasms with irregular borders. These tumors may occur alone or may be mixed with hepatocellular carcinomata. In the more well-differentiated forms, the tumors assume a relative degree of glandular organization with clearly visible tubules or ducts. In less well-differentiated forms, there is only a faint tendency to form ducts. The epithelia that constitute the tumor are cuboidal to squamous, often spindle-shaped cells embedded in a thin fibrous stroma. They are eosinophilic or amphophilic in well-differentiated lesions, but basophilic in poorly differentiated tumors. The nuclei are small (relative to those of hepatocytes), with reduced chromasia and indistinct nucleoli.

3.5.3.2 Preneoplastic Nodules--

Three distinct cellular lesions appear in the livers of mammals exposed to hepatocarcinogens: clear, eosinophilic, and basophilic nodules (Squire and Levitt 1975; Stewart et al. 1980). These lesions are recognized by their staining characteristics and by functional anomalies that can be detected histochemically. These lesion types may occur singly, in pairs, or all three simultaneously in a single liver. They may also be found in tissue that contains neoplasms. These foci typically measure 1.0 mm or less in diameter and are considered to represent preneoplastic steps in the development of hepatocellular carcinomas.

Clear Cell Focus--Clear cell foci are discrete, spherical nodules characterized by the apparent emptiness of their cellular cytoplasm. The cytoplasm of the constituent cells is filled with vacuoles that appear clear ("empty") when stained by conventional techniques (e.g., hematoxylin and eosin). The foci are distinct from the surrounding parenchymal cells even if they have a high degree of vacuolization. Histochemically, the cells may contain glycogen or lipid. The lesions do not compress the adjacent tissue.

Eosinophilic Nodule--Foci of hepatocytes characterized by intense eosinophilia are referred to as eosinophilic nodules (eosinophilic hypertrophy). These foci are spherical, non-compressing structures that blend imperceptibly into the surrounding muralia. In some systems, they elicit a pronounced inflammatory/immunological response. The foci contain hypertrophic hepatocytes having eosinophilic cytoplasm, but that otherwise have normal cellular characteristics. These foci typically do not contain MMCs. In trout, the intense eosinophilia has been shown to result from an abundance of smooth endoplasmic reticulum (Hendricks et al. 1984).

Basophilic Nodule--Basophilic nodules (hyperbasophilic foci) are discrete, spherical foci (0.1-1.0 mm in diameter) that contain small, basophilic hepatocytes. In trout, the basophilia has been shown to result from extensive quantities of granular endoplasmic reticulum and free ribosomes. The foci are non-compressing and grade imperceptibly into the adjacent parenchyma. They typically contain no MMCs and may have reduced hemosiderin levels in siderotic livers. These foci are believed to be a signal that neoplastic transformation is complete (Hendricks et al. 1984).

3.5.3.3 Megalocytic Hepatosis--

Megalocytic hepatosis is a degenerative lesion of the hepatocellular parenchyma that is characterized by a marked increase (two- to threefold) in the nuclear and cellular diameters of affected hepatocytes in the absence of cellular inflammatory responses (Malins et al. 1982). The nuclei of affected cells are vesicular and hyperchromatic, and the cytoplasm is generally eosinophilic and often shows associated changes such as hydropic degeneration or hyalinization. Megalocytic hepatosis is often found in association with altered MMCs, hemosiderois, or foci of hepatocellular regeneration. This change is considered to be a degenerative condition that results from toxic injury. It is not a proliferative lesion, nor is it considered to be a preneoplastic focus.

3.5.3.4 Nuclear Pleomorphism--

Nuclear pleomorphism is a condition occasionally seen in hepatic tissue undergoing degenerative changes. The condition, which occurs in hepatocytes, is characterized by increased nuclear diameter with no attendant increase in cellular diameter. Nuclei are not considered to be pleomorphic unless there is at least a threefold variation in nuclear diameter from the smallest to the largest nucleus in the tissue. This condition is considered to be degenerative and non-proliferative.

3.5.4 Effects of Sex

To determine whether any of the four kinds of liver lesions described previously occurred more frequently in male or in female English sole, the sex distribution of fish having each condition was compared with the sex distribution of all English sole examined from Commencement Bay (Table 3.32) using a 2x2 contingency formulation and the chi-square criterion. Sex distributions for all four lesion types were not significantly different ($P>0.05$) from the overall distribution in Commencement Bay (Table 3.32), indicating that both sexes were similarly affected by these disorders.

TABLE 3.32. COMPARISONS OF SEX DISTRIBUTIONS OF COMMENCEMENT BAY ENGLISH SOLE HAVING VARIOUS KINDS OF LIVER LESION WITH THE SEX DISTRIBUTION OF ALL ENGLISH SOLE SAMPLED IN COMMENCEMENT BAY[a,b]

Liver Lesion	Number (Percent) Having Each Condition Males		Females		Significance[c]
Hepatic neoplasms	20	(3.3)	5	(1.7)	ns
Preneoplastic nodules	76	(12.6)	38	(13.0)	ns
Megalocytic hepatosis	60	(10.0)	37	(12.9)	ns
Nuclear pleomorphisms	25	(4.2)	17	(5.9)	ns

[a] Overall Commencement Bay distribution was 601 males and 286 females.

[b] Comparisons were made using a 2x2 contingency formulation and the chi-square criterion. (Comparisonwise significance level = 0.0125).

[c] ns = P>0.05. (experimentwise).

3.5.5 Effects of Age

As noted in Section 2.6, Malins et al. (1982) and McCain et al. (1982) found that prevalences of liver lesion in English sole were substantially lower in younger than in older fish. Because of this age dependence, only larger (and thus older) English sole were subsampled for histopathological analysis in the present study (see Section 2.6). Using a 225-mm minimum size criterion, only 6 of the 950 (0.6 percent) English sole aged in this study were less than 3 yr old. Seventy (6.9 percent) fish could not be aged because their otoliths were either lost in the field or were unreadable.

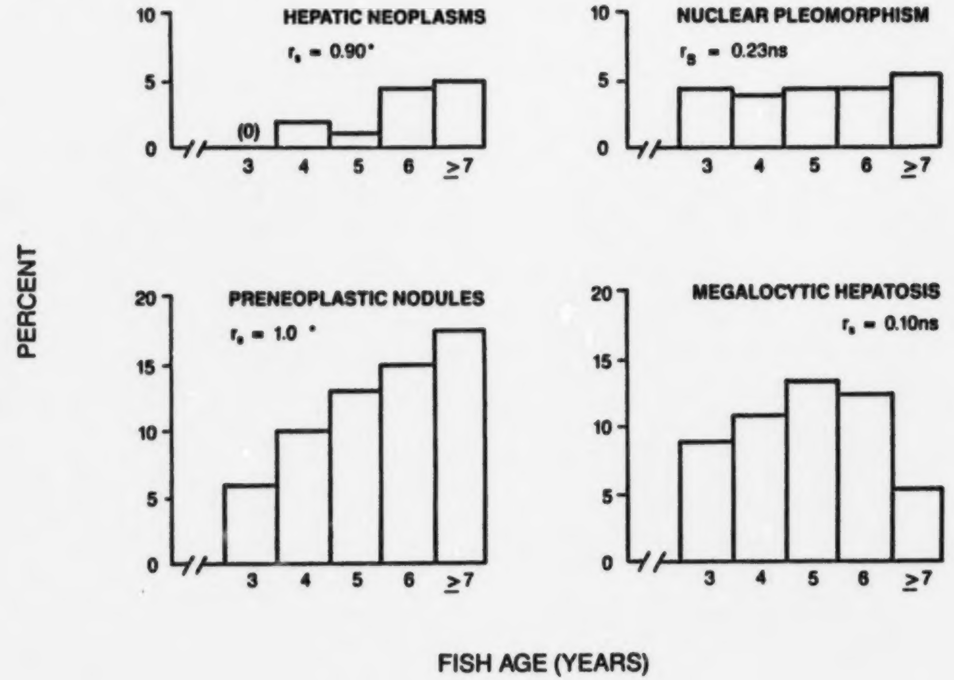
To determine whether prevalence of each of the four lesions considered in the present study showed a monotonic increase with age in the aged English sole (>2 yr old) subsampled from Commencement Bay (n=837), prevalence of each disorder was compared with fish age using Spearman's rank correlation coefficient (r_s). Because none of these disorders showed a sex-related bias (see Section 3.5.4), fish were not stratified by sex in this analysis.

Prevalences of hepatic neoplasms and preneoplastic nodules were significantly correlated ($P<0.05$) with fish age (Figure 3.56). Neoplasm prevalence ranged from 0 (age 3) to 5.0 (age $\geq$7) percent and, aside from a slight decline between ages 4 and 5, increased monotonically with fish age. Prevalences of preneoplastic nodules increased monotonically with age, ranging from 5.7 (age 3) to 17.5 (age $\geq$7) percent.

Prevalences of megalocytic hepatosis and nuclear pleomorphism did not correlate significantly ($P>0.05$) with fish age (Figure 3.56). Although prevalence of megalocytic hepatosis steadily increased from 9.1 to 13.5 percent between ages 3 and 5, it declined slightly to 12.6 percent at age 6 and then decreased dramatically to 5.6 percent at ages $\geq$7. By contrast, prevalence of nuclear pleomorphism was quite stable across age groups, ranging from 3.9 to 5.6 percent.

3.5.6 Spatial Patterns of Individual Disorders

The primary goal of the histopathological analysis was to determine whether English sole from Commencement Bay exhibited significantly different ($P<0.05$) prevalences of liver lesions than conspecifics from Carr Inlet (i.e., the reference site). Comparisons were made using a 2x2 contingency formulation and the chi-square criterion. Spatial patterns were considered on three scales: by embayment, by study area, and by trawl transect within each larger study area (Hylebos, Blair, and City Waterways, and the Ruston-Pt. Defiance Shoreline). Because the four lesions considered in this study did not show a sex bias (see Section 3.5.4), no corrections were made for differences in sex distributions between the reference site and Commencement Bay. By contrast, because three of the lesions were positively correlated with age (see Section 3.5.5), age distributions of English sole from Commencement Bay were compared with that in Carr Inlet before histopathological comparisons were made.



AGE GROUP	SAMPLE SIZE
3	88
4	178
5	229
6	182
7	160

Figure 3.56. Comparisons of prevalences of four liver disorders with age of English sole from Commencement Bay using the Spearman rank correlation coefficient (r_s). (Note: * = $P<0.05$, ns = $P>0.05$.)

To test for age differences between English sole in Commencement Bay and Carr Inlet, age distributions were compared between embayments using the Mann-Whitney U-test. Separate comparisons were made for each scale of analysis (i.e., by embayment, study area, and transect). Age distributions of English sole from all of Commencement Bay, from two study areas (Blair and Sitcum Waterways), and from three trawl transects within the larger study areas (BL70, BL71, and BL72) differed significantly ($P<0.05$) from the age distribution in Carr Inlet. In each case, median age was greater in Commencement Bay. To correct for these age differences, the largest fish from each Commencement Bay site were eliminated sequentially until the median age of the remaining distribution did not differ significantly ($P>0.05$) from that in Carr Inlet. Using this approach, 47 fish were eliminated from the total Commencement Bay sample, 46 and 1 fish were removed from the distributions in Blair and Sitcum Waterways (respectively), and 17, 9, and 3 fish were removed from the individual samples at Transects BL70, BL71, and BL72, respectively.

3.5.6.1 Patterns Based on Embayments--

Prevalences of the four lesion categories in age-corrected samples of English sole from Commencement Bay and Carr Inlet are presented in Figure 3.57. Occurrences of hepatic neoplasms and nuclear pleomorphism were restricted to Commencement Bay fish. The most frequently observed lesion categories in English sole from both areas were preneoplastic nodules and megalocytic hepatosis. Prevalences of three of the four liver conditions (preneoplastic nodules, megalocytic hepatosis, and nuclear pleomorphism) were significantly higher ($P<0.05$) in Commencement Bay than in Carr Inlet. On a bay-wide basis, the prevalence of hepatic neoplasms was not statistically elevated in Commencement Bay fish when compared to Carr Inlet. On a bay-wide basis, the prevalence of hepatic neoplasms was not statisticaly elevated in Commencement Bay fish when compared to Carr Inlet.

3.5.6.2 Patterns Based on Study Areas--

Prevalence of hepatic neoplasms was not significantly different ($P>0.05$) from that in Carr Inlet (0 percent) at any of the eight Commencement Bay study areas (Table 3.33). The highest incidence of hepatic neoplasms in Commencement Bay study areas (8.3 percent) was in Middle Waterway, whereas the lowest value (0 percent) was found along Ruston-Pt. Defiance Shoreline.

Prevalence of preneoplastic nodules was significantly different ($P<0.05$) from that in Carr Inlet (5.8 percent) only in Middle Waterway (26.7 percent). The lowest incidence of preneoplastic nodules in Commencement Bay study areas (6.6 percent) was found in Blair Waterway.

Prevalence of megalocytic hepatosis was significantly different ($P<0.05$) from that in Carr Inlet (0.8 percent) at four Commencement Bay study areas: Hylebos (18.3 percent), Milwaukee (16.7 percent), Middle (15.0 percent), and Blair (11.9 percent) Waterways. The lowest incidence of this disorder in Commencement Bay study areas (5.0 percent) was found in St. Paul Waterway.

As with preneoplastic nodules, prevalence of nuclear pleomorphism was significantly different ($P<0.05$) from that in Carr Inlet (0 percent) only in Middle Waterway (10.0 percent). Prevalences of this disorder in

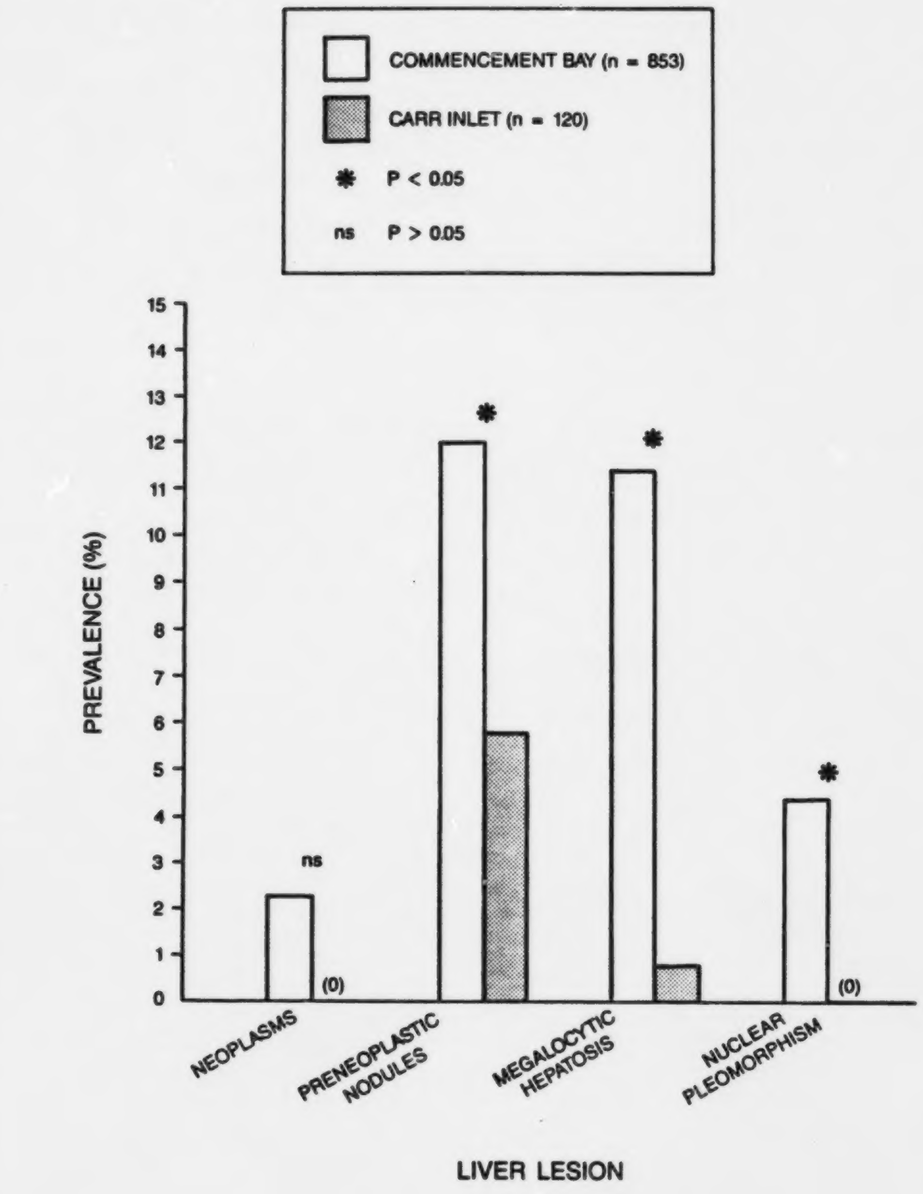


Figure 3.57. Comparisons of prevalences of six liver disorders between English sole from Commencement Bay and Carr Inlet using a 2 X 2 contingency test. (Critical chi-square = 3.84.)

TABLE 3.33. COMPARISONS OF PREVALENCES OF FOUR LIVER LESIONS BETWEEN ENGLISH SOLE FROM STUDY AREAS IN COMMENCEMENT BAY AND CARR INLET

Study Area	Sample Size[a]	Percent of Fish Having Each Condition[b]			
		Hepatic Neoplasms	Preneoplastic Nodules	Megalocytic Hepatosis	Nuclear Pleomorphism
Hylebos Waterway	180	2.8	13.3	18.3*	5.6
Blair Waterway	134 (180)	0.8 (3.3)	7.5 (9.4)	12.7* (11.1)	4.5 (6.1)
Sitcum Waterway	59 (60)	5.1 (5.0)	18.6 (18.3)	10.2 (10.0)	5.1
Milwaukee Waterway	60	3.3	15.0	16.7*	0
St. Paul Waterway	60	1.7	16.7	5.0	5.0
Middle Waterway	60	8.3	26.7*	15.0*	10.0*
City Waterway	120	0.8	8.3	6.7	3.3
Ruston-Pt. Defiance Shoreline	180	0	10.6	5.6	2.8
Carr Inlet[c]	120	0	5.8	0.8	0

[a] Sample sizes in Blair and Sitcum Waterways were reduced when age distributions were adjusted (see text for explanation). Unadjusted values are given in parentheses.

[b] An asterisk denotes that a prevalence was significantly different ($P<0.05$) from that at Carr Inlet. (Comparisonwise significance level = 0.0031).

[c] Reference area.

the remaining Commencement Bay study areas were less than 6 percent, with the lowest value (0 percent) found in Milwaukee Waterway.

English sole from Middle Waterway had the greatest number (3) of significantly elevated ($P<0.05$) liver lesions in Commencement Bay. These included preneoplastic nodules, megalocytic hepatosis, and nuclear pleomorphism. Fish from Hylebos, Blair, and Milwaukee Waterways had significantly elevated levels of only megalocytic hepatosis. Finally, fish from St. Paul and City Waterways and Ruston-Pt. Defiance Shoreline did not have significantly elevated levels of any of the four lesions considered.

3.5.6.3 Patterns Based on Trawl Transects--

Prevalences of hepatic neoplasms, preneoplastic nodules, and nuclear pleomorphism were not significantly different ($P>0.05$) from those in Carr Inlet at any of the 11 trawl transects in Commencement Bay (Table 3.34). Transects having the highest prevalence of each disorder were HY71 (neoplasms - 6.7 percent), RS70 (preneoplastic nodules - 18.3 percent), and HY70 (nuclear pleomorphism - 8.3 percent).

Prevalence of megalocytic hepatosis was significantly different ($P<0.05$) from that in Carr Inlet at all three transects in Hylebos Waterway (HY70, 71, and 72), at two of the three transects in Blair Waterway (BL70 and 71), and at one of the three transects along Ruston-Pt. Defiance Shoreline (RS70). The highest incidence of this disorder at a trawl transect within a Commencement Bay study area (26.7 percent) was at HY70, and the lowest value (0 percent) was at RS71.

When lesion prevalence in areas with multiple trawl samples is examined on a trawl sample basis rather than on an overall area basis, the only differences occurred in Blair Waterway and along the Ruston-Pt. Defiance Shoreline. In these two areas, there is evidence of spatial gradients in the prevalences of megalocytic hepatosis. Although Blair Waterway had an overall significant elevation in megalocytic hepatosis, the prevalence of this lesion was low and not significantly different from Carr Inlet ($P>0.05$) near the waterway mouth. Along the Ruston-Pt. Defiance Shoreline the overall prevalence of megalocytic hepotosis was not significantly elevated. However, the individual trawl site nearest the mouth of City Waterway displayed a statistically significant elevation ($P<0.05$) in the lesion prevalence.

3.5.7 Spatial Patterns of Fish Having One or More Major Lesion

To construct a single index representing the prevalence of possible contaminant-induced liver lesions in English sole from Commencement Bay and Carr Inlet, the number of fish having one or more of the four liver lesions was calculated. Because many fish were afflicted with more than one type of lesion, the number of fish having one or more of the four lesions is less than would be calculated by simply summing the prevalences of the individual lesion types. This index thus represents the actual number of afflicted fish, rather than the number of afflictions. Comparisons between prevalences of fish having one or more major lesions in Commencement Bay and Carr Inlet were made using a 2x2 contingency formulation and the chi-square criterion.

TABLE 3.34. COMPARISONS OF PREVALENCES OF FOUR LIVER LESIONS BETWEEN ENGLISH SOLE FROM TRAWL TRANSECTS IN COMMENCEMENT BAY AND CARR INLET

Trawl Transect	Sample Size[a]	Percent of Fish Having Each Condition[b]			
		Heptatic Neoplasms	Preneoplastic Nodules	Megalocytic Hepatosis	Nuclear Pleomorphism
HY70	60	0	13.3	26.7*	8.3
HY71	60	6.7	15.0	15.0*	0.5
HY72	60	1.7	11.7	13.3*	3.3
BL70	43	2.3	11.6	14.0*	7.0
	(60)	(8.3)	(16.7)	(13.3)	(10.0)
BL71	51	0	5.9	19.6*	5.9
	(60)	(0)	(8.3)	(16.7)	(5.0)
BL72	57	0	3.5	3.5	1.8
	(60)	(1.7)	(3.3)	(3.3)	(3.3)
CI70	60	1.7	6.7	10.0	5.0
CI72	60	0	10.0	3.3	1.7
RS70	60	0	18.3	11.7*	5.0
RS71	60	0	8.3	0	0
RS72	60	0	5.0	5.0	3.3
CR70 and 71[c]	120	0	5.8	0.8	0

[a] Sample sizes in Blair Waterway were reduced when age distributions were adjusted (see text for explanation). Unadjusted values are given in parentheses.

[b] An asterisk denotes that a prevalence was significantly different ($P<0.05$) from that at Carr Inlet. (Comparisonwise significance level = 0.0023).

[c] Reference area.

Prevalence of fish having one or more lesions was significantly different ($P<0.05$) from that in Carr Inlet (6.7 percent) at five of the eight Commencement Bay study areas (Figure 3.58): Hylebos, Blair, Sitcum, Milwaukee, and Middle Waterways. Prevalence in Commencement Bay study areas was highest (40.0 percent) in Middle Waterway and lowest (13.3 percent) in City Waterway.

Within the larger Commencement Bay study areas (i.e. Hylebos, Blair, and City Waterways, and the Ruston-Pt. Defiance Shoreline), prevalence of fish having one or more lesions (Figure 3.58) was significantly different ($P<0.05$) from that in Carr Inlet at all three trawl transects in Hylebos Waterway (HY70, 71, and 72), at two transects in Blair Waterway (BL70 and 71), and at one transect along Ruston-Pt. Defiance Shoreline (RS70). Prevalence at Commencement Bay transects was highest (33.3 percent) at HY70 and lowest (7.0 percent) at BL72.

In general, prevalences of fish having one or more lesions at trawl transects showed patterns similar to those of their respective larger study area. However, there were two exceptions. First, prevalence at BL72 (7.0 percent) was almost as low as that in Carr Inlet, whereas prevalence in the entire Blair Waterway (20.9 percent) was significantly different ($P<0.05$) from that at the reference area. By contrast, prevalence at RS70 (26.7 percent) was significantly different ($P<0.05$) from that at Carr Inlet, whereas overall prevalence along Ruston-Pt. Defiance Shoreline (15.6 percent) was not significantly different ($P>0.05$) from that at the reference area.

3.5.8 Fish Condition Comparisons

To examine whether Commencement Bay English sole with hepatic lesions exhibited reduced condition (see Section 3.4.3.4) relative to conspecifics without these lesions, weight-at-length (WAL) values of these two groups (stratified by sex) were compared using regression analysis. Weight and length values for all fish were log-transformed and least-squares linear regression lines were calculated (cf. Ricker 1975). Regression lines for fish with and without lesions were tested for coincidence using the Z test (Kleinbaum and Kupper 1978).

For both sexes, the slopes and y-intercepts of the regression equations for fish with and without hepatic lesions did not differ significantly ($P>0.05$, Table 3.35). Each pair of regression lines can therefore be considered coincident. Thus, English sole with hepatic lesions did not exhibit reduced condition relative to conspecifics without lesions.

3.5.9 Comparisons with Historical Data

Most historical studies of liver disorders in English sole from Puget Sound have been conducted by Dr. Donald C. Malins and his associates at the Environmental Conservation Division of the Northwest and Alaska Fisheries Center of NMFS. As mentioned previously (Section 2.6), all abnormal liver conditions observed in the present study were independently verified by the chief pathologist of Malins' group. Although this intercalibration procedure ensured that consistent classifications of liver disorders were made, direct comparisons of results of the present study with data collected in the past by Malins et al. (1980, 1982, 1984) are limited by several additional factors. First, and perhaps foremost, is the fact that Malins

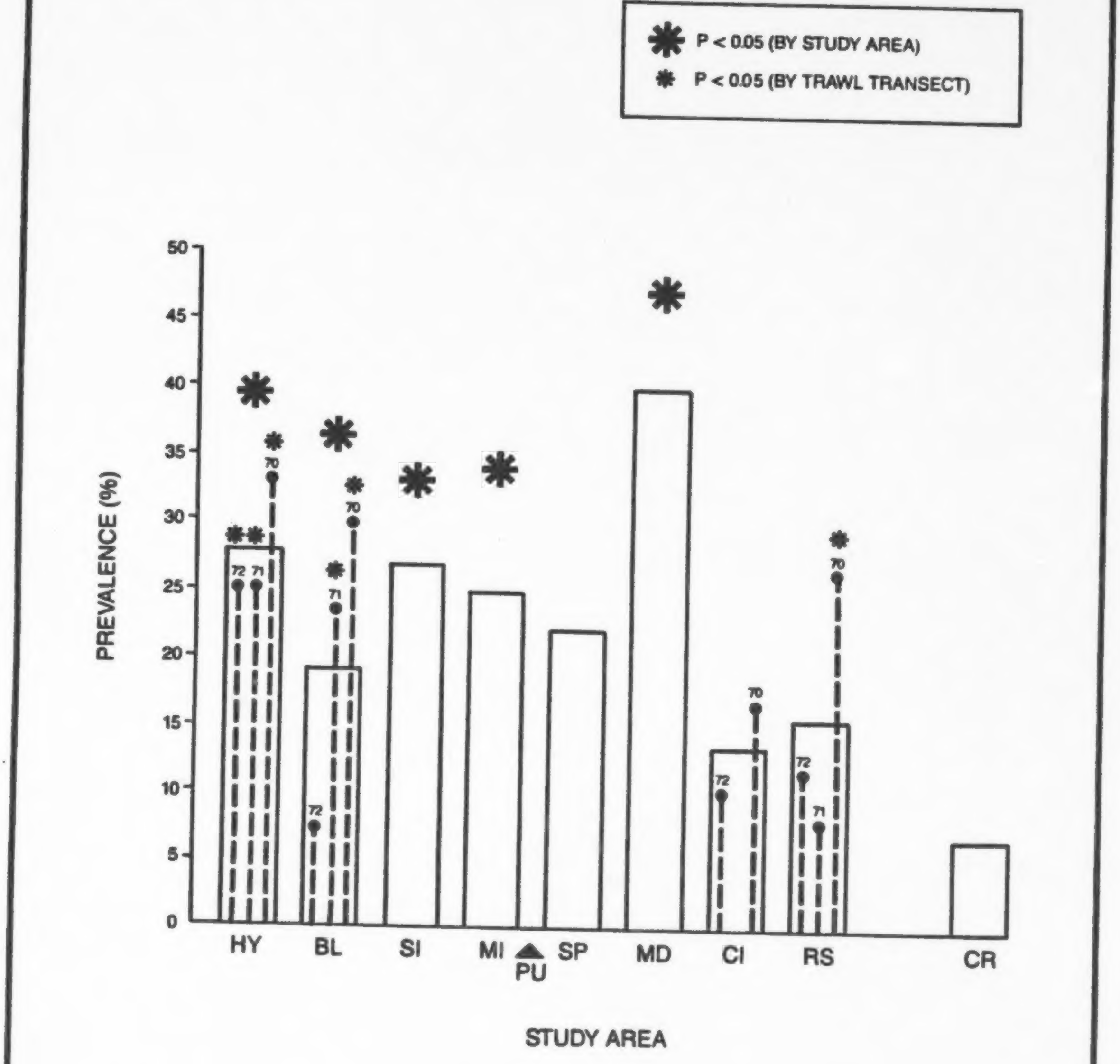


Figure 3.58. Comparisons of prevalences of one or more of four major hepatic lesions in English sole from Commencement Bay and Carr Inlet using a 2 X 2 contingency test.

TABLE 3.35. COMPARISONS OF WEIGHT-LENGTH REGRESSION COEFFICIENTS[a] BETWEEN ENGLISH SOLE WITH LESIONS AND CONSPECIFICS WITHOUT LESIONS

Sex	Lesion[b]	Number of fish[c]	Slope[d]		Y-Intercept[e]	
			b(S.E.)	Significance	a(S.E.)	Significance
Male	absent	471	2.68 (0.045)	ns	-4.32 (0.109)	ns
	present	130	2.65 (0.088)		-4.24 (0.214)	
Female	absent	217	2.66 (0.066)	ns	-4.22 (0.162)	ns
	present	69	2.74 (0.101)		-4.44 (0.248)	

[a] Regression equations were based on log-transformed weights and lengths, and comparisons were stratified by sex.

[b] Presence or absence of one or more of the following hepatic lesions: neoplasms, preneoplastic nodules, megalocytic hepatosis, and nuclear pleomorphisms.

[c] Only fish from Commencement Bay were considered.

[d] The slopes (b) for each sex were compared using the Z test. The standard error (S.E.) of each slope is given in parentheses. ns = P>0.05.

[e] The y-intercepts (a) for each sex were compared using the Z test. The standard error (S.E.) of each intercept is given in parentheses. ns = P>0.05.

et al. (1980, 1982, 1984) included all age groups of English sole (including fish less than 3 yr old) when calculating prevalences, whereas, by design, almost all of the 950 fish aged in the present study (99.4 percent) were at least 3 yr old. As shown by Malins et al. (1982), McCain et al. (1982), and the present study (see Section 3.5.5), several liver conditions are positively related to fish age. Thus, prevalences reported in the present study are likely to be substantially higher than those found by Malins et al. because of the exclusion of the youngest fish (i.e., <3 years old) from the present study.

A second major limitation to intercomparisons with historical data arises from differences in sampling locations. As shown in the present study, prevalences of liver disorders can vary dramatically over relatively short distances. For example, the incidence of megalocytic hepatosis declined by 11.7 percent between Transects HY70 and HY71 in Hylebos Waterway and by 16.1 percent between Transects BL71 and BL72 in Blair Waterway (Table 3.32).

A third type of limitation to intercomparisons with historical data is based on temporal differences. It is likely that seasonal or interannual differences among studies would influence observed prevalences to some degree. For instance, Malins et al. (1980) found that prevalence of megalocytic hepatosis in English sole at Commencement Bay stations declined from winter to summer, and then increased in fall. In addition, McCain et al. (1982) found a significant decrease in the prevalence of hepatic neoplasms in English sole from Sitcum Waterway between 1979 and 1983.

Given the above limitations, results of the present study and those found by Malins et al. (1984) were only compared qualitatively. Prevalences of the four lesions considered earlier (i.e., hepatic neoplasms, preneoplastic nodules, megalocytic hepatosis, and nuclear pleomorphism) were compared between the present study and that of Malins et al. (1984) at the three areas of Commencement Bay common to both studies (Figure 3.59). Although Malins et al. (1980) did not sample fish in Carr Inlet, two of their reference stations were located in an adjacent embayment, Case Inlet. Because these two embayments are morphologically similar, prevalences of liver disorders were compared between them. Because Malins et al. (1980) pooled the prevalences of nuclear pleomorphism with those of megalocytic hepatosis (Myers, M., 9 January 1985, personal communication), data from the present study were modified in a similar manner. Results from Malins et al. (1984) were taken from Table III, and represent data pooled across four sampling periods (winter, spring, summer, and fall) from 1979 to 1982.

As expected, prevalences of all three liver lesions generally were higher in the present study than were those found by Malins et al. (1984; Figure 3.59). However, the relative magnitudes of each condition across different areas was quite similar between studies. In general, prevalence of each disorder was at or close to 0 percent in Carr and Case Inlets. The one exception was preneoplastic nodules in Carr Inlet, where a prevalence of approximately 6 percent was found in the present study. For both studies, prevalences of all three lesions reached their highest respective levels in either Hylebos Waterway or the remaining Commencement Bay waterways. Finally, prevalences along the Ruston-Pt. Defiance Shoreline of all three lesions in both studies were intermediate in magnitude between prevalences in the reference areas and those in the waterways.

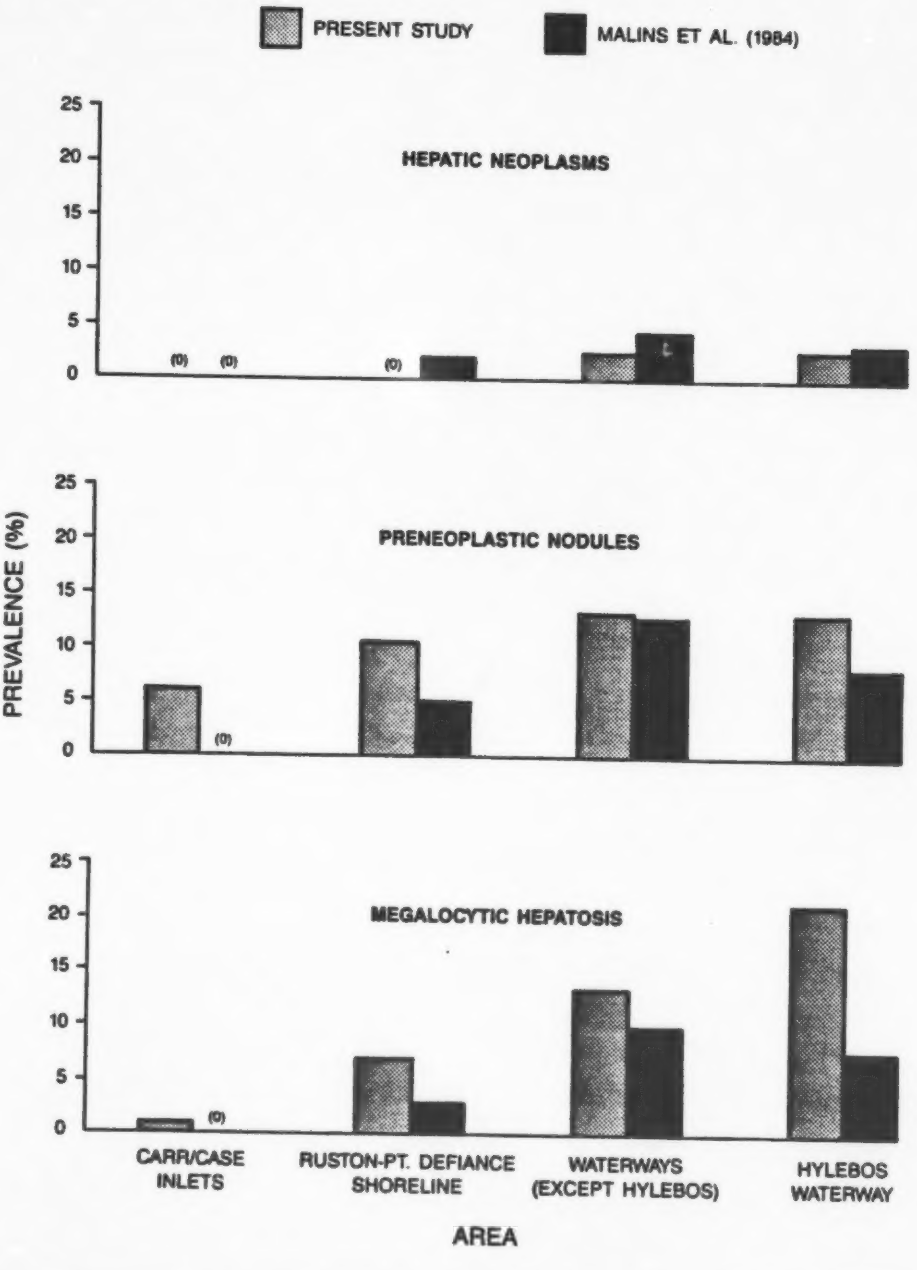


Figure 3.59. Comparison of prevalences of hepatic lesions in English sole sampled in the present study and in Malins et al. (1984).

The observed similarities between the spatial distributions of the the three hepatic lesions found in the present study and those found by Malins et al. (1984) 2-5 yr earlier imply that these patterns are real (not spurious) and that they are quite stable temporally. This suggests that the causes of the lesions may be localized within the overall study area.

Because most adult English sole migrate to deeper water in winter (Ketchen 1956; Miller et al. 1977), it is somewhat surprising that this movement does not obscure the observed spatial patterns of lesion prevalence. There exist several possible explanations for the persistence of these patterns. First, fish having lesions may not migrate. If the lesions indicate that a fish is in poor health, it is possible that affected individuals do not have the stamina to undertake migration. However, this explanation does not seem plausible because of the apparently normal condition factors of English sole with hepatic lesions. A second possibility is that the same individuals return to the same locality every year following overwintering. Although English sole have exhibited some degree of homing ability (Day 1976), the precision with which these fish can relocate a localized area is unknown. A third possibility is that lesions are rapidly induced in a single season. Thus, an individual would only have to enter a lesion-causing area during a single migration cycle, rather than returning year after year, or permanently residing in the area. The strong age dependence of hepatic neoplasms and preneoplastic nodules suggests that exposure to lesion inducers must occur over several years. However, it could be that older fish are less resistant to lesion induction (e.g., as part of senescence) and therefore exhibit higher lesion prevalences than younger individuals after a single exposure period. Although the lesion induction process in English sole cannot be explained at present, it seems clear from this study and Malins et al. (1984) that this process is highly dependent upon spatial locations.

3.5.10 Summary

- Four kinds of hepatic lesions were considered in this study: hepatic neoplasms, preneoplastic nodules, megalocytic hepatosis, and nuclear pleomorphism.

- For all data pooled within Commencement Bay, prevalences of preneoplastic nodules, megalocytic hepatosis, and nuclear pleomorphism were significantly elevated ($P<0.05$) compared to prevalences in Carr Inlet.

- Based on the eight Commencement Bay study areas, prevalences of preneoplastic nodules and nuclear pleomorphism were significantly elevated ($P<0.05$) only in Middle Waterway, and prevalence of megalocytic hepatosis was significantly elevated ($P<0.05$) in Hylebos, Blair, Milwaukee, and Middle Waterways.

- Based on individual trawl transects within the larger study areas (i.e., Hylebos, Blair, and City Waterways, and the Ruston-Pt. Defiance Shoreline), prevalence of megalocytic hepatosis was significantly elevated ($P<0.05$) at all transects in Hylebos Waterway (HY70, 71, and 72), at two transects in Blair Waterway (BL 70 and 71), and at Transect RS70 along the Ruston-Pt. Defiance Shoreline.

- Prevalences of hepatic neoplasms were not significantly elevated ($P<0.05$) for all data pooled within Commencement Bay, the eight study areas, or the individual trawl transects when compared with prevalences in Carr Inlet.

- Prevalence of fish having one or more of the four hepatic lesions was significantly elevated in Hylebos, Blair, Sitcum, Milwaukee, and Middle Waterways (based on study areas) and at HY71, HY72, BL71, BL72, and RS70 (based on trawl transects within the larger study areas). Spatial patterns based on fish having significantly elevated ($P<0.05$) prevalences of one or more of the four lesions are summarized in Figure 3.60.

- Results of the present study were compared with historical data collected by Malins et al. (1984). Absolute values of the prevalences of hepatic neoplasms, preneoplastic nodules, and megalocytic hepatosis in the present study were generally larger than those found by Malins et al. (1984). However, this discrepancy may be largely the result of different age distributions of English sole sampled by the two studies. By contrast with absolute values, the relative magnitudes of lesions prevalences across areas were very similar between the two studies. In both studies, prevalences were lowest at reference sites, highest in the Commencement Bay waterways, and intermediate in magnitude along the Ruston-Pt. Defiance Shoreline.

3.6 BIOACCUMULATION

3.6.1 Introduction

Bioaccumulation studies were conducted as part of this investigation to determine if sediment or water contaminants are accumulated in the tissues of indigenous organisms. The specific objectives of these studies were to:

- Determine if measurable concentrations of priority pollutants and other substances (as were measured in sediment samples) are present in organism tissues

- Determine if there are statistically significant elevations in measured tissue contaminants in the Commencement Bay study area when compared with the Carr Inlet reference area

- Collect data for use in an endangerment assessment to assess risks to public health from ingestion of contaminated seafood

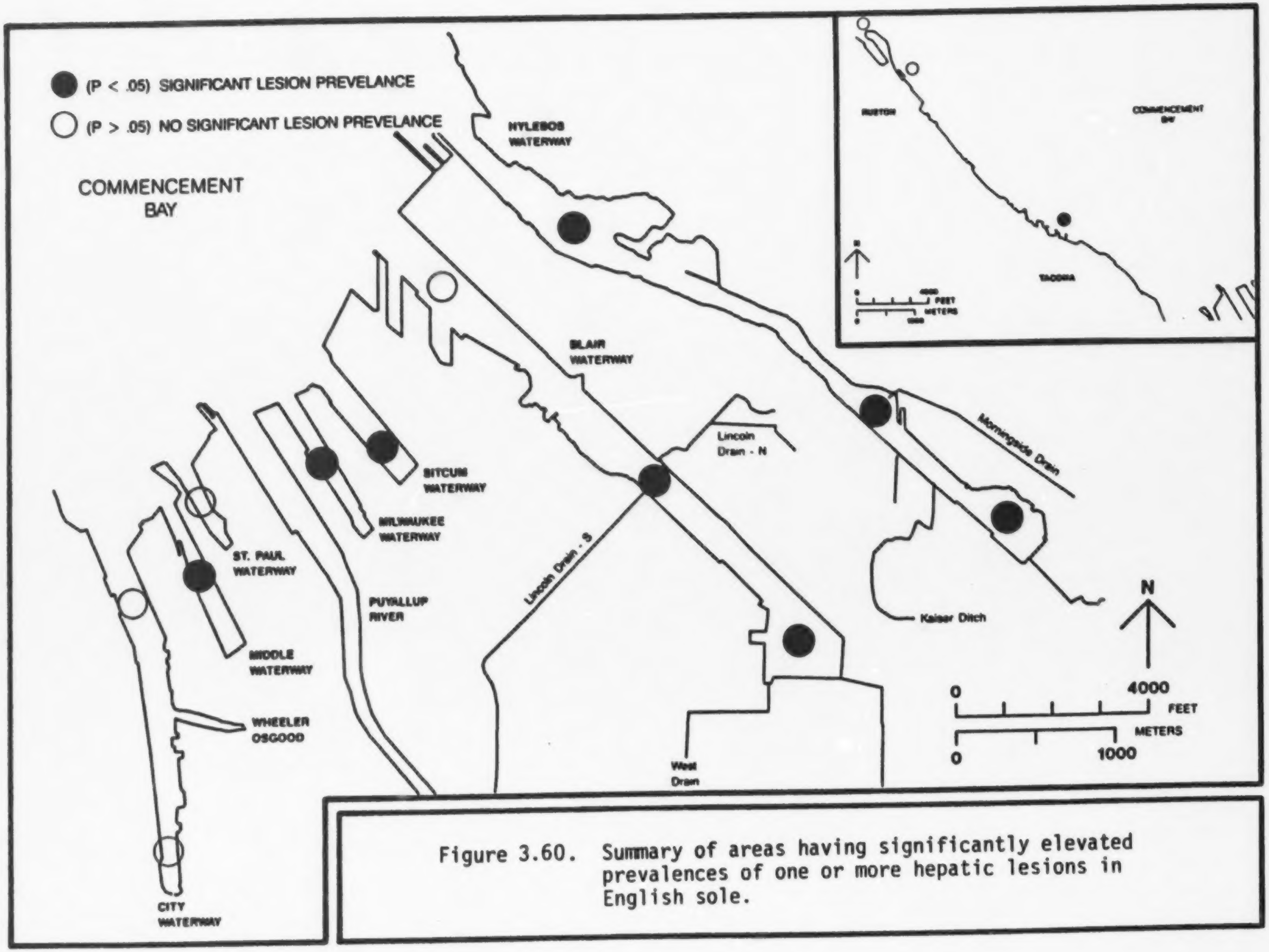

(P < .05) SIGNIFICANT LESION PREVELANCE
(P > .05) NO SIGNIFICANT LESION PREVELANCE
COMMENCEMENT BAY
HYLEBOS WATERWAY
BLAIR WATERWAY
Lincoln Drain - N
Lincoln Drain - S
Morningside Drain
Kaiser Ditch
West Drain
SITCUM WATERWAY
MILWAUKEE WATERWAY
ST. PAUL WATERWAY
PUYALLUP RIVER
MIDDLE WATERWAY
WHEELER OSGOOD
CITY WATERWAY
N
0
4000
FEET
METERS
0
1000
RUSTON
COMMENCEMENT BAY
TACOMA

Figure 3.60. Summary of areas having significantly elevated prevalences of one or more hepatic lesions in English sole.

- Collect data for use in the decision-making approach to identify and prioritize problem areas within Commencement Bay.

Bioaccumulation studies were conducted on two species: English sole (*Parophrys vetulus*) and cancrid crabs (*Cancer* spp). English sole were selected for study because they live in *direct* contact with the sediments, are relatively sedentary (compared to pelagic fish species), are abundant in the waterways, and have been shown in previous studies (e.g., Gahler et al. 1982) to accumulate sediment contaminants. Cancrid crabs also live in direct contact with the sediments and provide an assessment of possible differences between bioaccumulation in fishes and crustacea.

3.6.2 Metals in Fish Muscle

Results of analyses of inorganic substances in English sole muscle tissue are presented in Table 3.36. In general, the concentrations were relatively homogeneous among study areas, and there were few cases in which Commencement Bay fish displayed elevated concentrations relative to Carr Inlet reference values. Statistical analyses using the Kruskal-Wallis test indicated no significant ($P>0.05$) overall differences in tissue concentrations among study areas for the following inorganic substances: antimony, cadmium, chromium, nickel, and zinc. Several inorganic substances (i.e., arsenic, lead, and silver) actually displayed significantly ($P<0.05$) lower concentrations in some Commencement Bay fish when compared with reference concentrations.

The only two metals with significantly elevated tissue concentrations in any Commencement Bay area relative to Carr Inlet were mercury and copper (Table 3.36). Although mercury displayed relatively little overall variability among areas (i.e., average concentrations of 42-87 ug/kg wet weight), its within-area variability was also low. English sole from Hylebos Waterway had significantly higher mercury levels than conspecifics from Carr Inlet, even though the tissue mercury levels were only elevated by about 1.5 times (81 vs. 55 ug/kg wet weight). No other study areas had significantly elevated mercury levels when compared with reference values. Copper concentrations were significantly elevated in fish from Sitcum and St. Paul Waterways and the Ruston-Pt. Defiance Shoreline. Highest average copper concentrations (346 ug/kg wet weight) occurred in fish from St. Paul Waterway.

Because of its widespread presence in Commencement Bay sediments, arsenic was of special concern relative to potential bioaccumulation in resident fishes. The results of this study indicate that arsenic is not being accumulated by English sole in Commencement Bay at levels higher than would be expected in uncontaminated areas of Puget Sound. Most of the English sole collected in this study had muscle arsenic levels of 1-10 mg/kg wet weight, with occasional higher concentrations of 15-32 mg/kg wet weight. The highest average arsenic concentration (7.9 mg/kg wet weight) was measured in English sole from Carr Inlet. This high value resulted in part from the fact that the overall maximum arsenic concentration of 32 mg/kg wet weight was also detected in the Carr Inlet samples. Statistical analyses indicated that English sole from Hylebos, City, Milwaukee, and Sitcum Waterways had significantly ($P<0.05$) lower muscle arsenic concentrations than English sole from Carr Inlet.

TABLE 3.36. MEAN CONCENTRATIONS (mg/kg WET WEIGHT) OF INORGANIC SUBSTANCES IN ENGLISH SOLE MUSCLE TISSUE

	Arsenic	Cadmium	Chromium	Copper	Lead	Nickel	Silver	Zinc	Mercury
Carr Inlet	7.9	<0.02[a]	<0.19	U0.038[b]	0.22	<0.115	0.008	3.7	<0.055
Hylebos Waterway	<3.0	<0.03	<0.24	<0.212	<0.25	<0.100	<0.032	3.2	0.081[c]
Blair Waterway	6.7	<0.02	<0.19	<0.038	0.26	<0.090	0.015	4.1	<0.051
Sitcum Waterway	<1.6	<0.03	<0.14	0.154[c]	<0.14	<0.080	<0.002	3.4	<0.044
Milwaukee Waterway	2.1	<0.01	<0.17	<0.089	<0.14	<0.086	<0.002	3.2	0.087
St. Paul Waterway	<1.5	<0.03	0.21	0.346[c]	<0.14	U0.075	0.006	3.2	<0.042
Middle Waterway	2.3	<0.05	U0.14	<0.040	<0.15	U0.075	<0.003	3.2	0.072
City Waterway	3.0	<0.03	<0.20	<0.145	0.35	<0.086	0.009	3.6	<0.045
Ruston-Pt. Defiance Shoreline	<6.3	<0.01	<0.20	<0.096[c]	<0.16	<0.148	<0.002	3.9	<0.053

[a] < = Undetected in at least one sample. Detection limit used in calculation of mean.

[b] U = Undetected at detection limit shown.

[c] Indicates area significantly higher (P<0.05) than Carr Inlet reference area.

3.6.3 Metals in Crab Muscle

Crabs were relatively rare in the Commencement Bay Waterways and too few were collected to obtain replicate samples at all sites. Dungeness crabs were rare and could not be collected consistently for tissue analysis. Therefore, rock crabs (Cancer spp.) were collected for tissue analyses in many areas. Because of these limitations, statistical analysis of the crab bioaccumulation data is not appropriate. Inspection of the mean values for the crab data indicates, however, that the concentrations of most inorganic substances were relatively homogeneous among sampling sites (Table 3.37).

Arsenic concentrations were less variable in the tissues of crabs than in those from English sole, with individual muscle tissue concentrations ranging from 0.75 to 3.5 mg/kg wet weight. Mean arsenic concentrations from the waterways (1.2-2.9 mg/kg wet weight) displayed no apparent elevations relative to the Carr Inlet samples (average of 2.4 mg/kg wet weight). Crab muscle concentrations of chromium, copper, nickel, silver, and zinc displayed similar patterns. For these metals, mean concentrations in crabs from Commencement Bay were not more than about two times the Carr Inlet reference concentration. A single crab from St. Paul Waterway had a cadmium concentration of 0.620 mg/kg wet weight, about four times the average Carr Inlet cadmium concentration. This value is within the overall range of cadmium concentrations observed in Carr Inlet, however, and would not be considered as evidence of elevated cadmium bioaccumulation in St. Paul Waterway.

Lead and mercury data for crabs indicate possible elevation of tissue concentrations in the waterways. The lead concentrations in crabs from Sitcum and City Waterways were about 4.6 and 2.6 times higher, respectively, than the Carr Inlet values (Table 3.37). Maximum lead concentrations in these two areas (City, 1.65 mg/kg wet weight; Sitcum, 2.05 mg/kg dry weight) were well above the range observed in Carr Inlet (0.14-0.35 mg/kg wet weight).

Although only one crab sample was collected from Hylebos Waterway, its mercury concentration (0.220 mg/kg wet weight) was about five times the average concentration measured in Carr Inlet samples. It should be noted that maximum mercury concentrations in Milwaukee and Sitcum Waterways also exceeded 0.2 mg/kg wet weight.

3.6.4 Organic Compounds in Fish Muscle

Of the 100 U.S. EPA organic priority pollutants analyzed for, 84 were not detected in any of the English sole or crab samples analyzed. A list of the undetected compounds and their analytical detection limits is presented in Table 3.38.

Although high molecular weight PAH (HPAH) occurred in sediments of some waterways at concentrations up to 1,000 times beyond reference concentrations,HPAH were not detected in any of the 85 fish muscle tissue samples. Detection limits for HPAH were typically 10 ug/kg wet weight. The absence of these compounds in fish tissue is expected due to their rapid metabolism by the mixed-function-oxidase system. PAH metabolites were not analyzed as part of this study. However, available evidence indicates that HPAH

TABLE 3.37. MEAN CONCENTRATIONS (mg/kg WET WEIGHT) OF INORGANIC SUBSTANCES IN CRAB MUSCLE TISSUE

	Species[a]	n	Arsenic	Cadmium	Chromium	Copper	Lead	Nickel	Silver	Zinc	Mercury
Carr Inlet	R	7	2.4	0.148	<0.24[b]	8.1	<0.20	<0.107	0.197	47.4	<0.045
Hylebos Waterway	R	1	2.0	0.015	0.26	9.1	0.23	0.220	0.028	44.0	0.220
Blair Waterway	D	1	1.2	0.092	0.22	4.9	0.18	U0.076[c]	0.130	43.0	U0.040
Sitcum Waterway	D	4	2.1	0.048	0.26	8.3	0.93	U0.075	0.139	37.7	0.167
Milwaukee Waterway	D	5	1.3	<0.013	U0.14	7.9	0.31	U0.075	0.160	36.2	<0.110
St. Paul Waterway	R	1	1.5	0.620	0.25	6.1	0.14	U0.075	0.073	36.0	U0.040
Middle Waterway	M	2	1.9	0.175	0.25	9.0	0.32	<0.127	0.129	42.0	<0.050
City Waterway	M	5	2.9	0.083	0.22	7.2	0.53	U0.075	0.157	43.8	0.068

[a] Species: D = Dungeness crab, R = rock crab, M = mixed species.

[b] U = Undetected in at least one sample. Detection limit used in calculation of mean.

[c] U = Undetected at the detection limit shown.

TABLE 3.38. U.S. EPA PRIORITY POLLUTANTS NOT DETECTED IN ANY FISH OR CRAB MUSCLE TISSUE SAMPLE AT ANY OF 17 TRAWL TRANSECTS

Phenols (acids; 2 of 2)	Typical Detection Limit[a]
phenol	U 20
2,4-dimethylphenol	U 20
Substituted Phenols (acids; 8 of 9)	
2,4,6-trichlorophenol	U 20
p-chloro-m-cresol	U 20
2-chlorophenol	U 20
2,4-dichlorophenol	U 20
2-nitrophenol	U 20
4-nitrophenol	U 100
2,4-dinitrophenol	U 100
4,6-dinitro-2-methylphenol	U 25
Low Molecular Weight Aromatic Hydrocarbons (neutrals; 5 of 6)	
acenaphthene	U 10
acenaphthylene	U 10
anthracene	U 10
phenanthrene	U 10[b]
fluorene	U 10
High Molecular Weight PAH (neutrals; 10 of 10)	
fluoranthene	U 10[b]
benzo(a)anthracene	U 10
benzo(a)pyrene	U 10
benzo(b)fluoranthene	U 10
benzo(k)fluoranthene	U 10
chrysene	U 10
benzo(g,h,i)perylene	U 10
dibenzo(a,h)anthracene	U 10
indeno(1,2,3-c,d)pyrene	U 10
pyrene	U 10
Chlorinated Aromatic Hydrocarbons (neutrals; 4 of 6)	
1,2,4-trichlorobenzene	U 20
2-chloronaphthalene	U 10
1,2-dichlorobenzene	U 20
1,4-dichlorobenzene	U 20
Chlorinated Aliphatic Hydrocarbons (neutrals; 2 of 3)	
hexachloroethane	U 40
hexachlorocyclopentadiene	N/A

TABLE 3.38. (Continued)

Halogenated Ethers (neutrals; 5 of 5)	
bis(2-chloroethyl)ether	U 20
4-chlorophenylphenylether	U 20
4-bromophenylphenylether	U 20
bis(2-chloroisopropyl)ether	U 20
bis(2-chloroethoxy)methane	U 20
Miscellaneous oxygenated compounds (neutrals; 2 of 2)	
2,3,7,8-tetrachlorodibenzo-p-dioxin	N/A
isophorone (3,5,5-trimethyl-2-cyclohexene-1-one)	U 10
Organonitrogen Compounds (bases; 8 of 8)	
benzidine (4,4'-diaminobiphenyl)	N/A
3,3'-dichlorobenzidine	N/A
2,4-dinitrotoluene	U 20
2,6-dinitrotoluene	U 20
1,2-diphenylhydrazine (hydrazobenzene)	U 10
nitrobenzene	U 20
n-nitrosodiphenylamine	U 10
n-nitrosodipropylamine	U 20
Pesticides (neutrals; 18 of 18)	
aldrin	U 50
dieldrin	U 50
chlordane	U 50
4,4'-DDT	U 50
4,4'-DDE	U 50
4,4'-DDD	U 50
alpha-endosulfan	U 50
beta-endosulfan	U 50
endosulfan sulfate	U 50
endrin	U 50
endrin aldehyde	U 50
heptachlor	U 50
heptachlor epoxide	U 50
alpha-HCH	U 50
beta-HCH	U 50
delta-HCH	U 50
gamma-HCH	U 50
toxaphene (camphechlor)	U 50

TABLE 3.38. (Continued)

Volatile Halogenated Alkanes (neutrals; 16 of 17)	
carbon tetrachloride	U 5
1,2-dichloroethane	U 10
1,1,1-trichloroethane	U 5
1,1-dichloroethane	U 5
1,1,2-trichloroethane	U 5
1,1,2,2-tetrachloroethane	U 5
chloroethane	U 10
chloroform	U 5
1,2-dichloropropane	U 10
methylene chloride (dichloromethane)	NR
chloromethane	U 10
bromomethane	U 10
bromoform	U 10
bromodichloromethane	U 10
dichlorodifluoromethane	U 10[c]
chlorodibromomethane	U 5
Volatile Halogenated Alkenes (neutrals; 5 of 6)	
1,1-dichloroethene	U 10
trans-1,2-dichloroethene	U 5
cis and trans-1,3-dichloropropene	U 10
trichloroethene	U 5
vinyl chloride	U 10
Volatile Aromatic Hydrocarbons (neutrals; 1 of 3)	
benzene	U 5
Volatile Chlorinated Aromatic Hydrocarbons (neutrals; 1)	
chlorobenzene	U 5
Volatile Unsaturated Carbonyl Compounds (base/neutrals; 2)	
acrolein (an unsaturated aldehyde)	U 100
acrylonitrile (an unsaturated nitrile)	U 100
Volatile Ethers (neutrals; 2)	
2-chloroethylvinyl ether	U 100

[a] U = Undetected at the detection limit stated (ug/kg or ppb wet weight tissue).
NR = Not reported or all data rejected during QA review.
N/A = Not analyzed.

[b] Detected at <50 ppb in a single crab at MD-70C.

[c] Removed from priority pollutant list.

metabolites are present primarily in the liver and bile, which are the primary sites of metabolism and excretion (Stein et al. 1984).

Sixteen organic compounds were detected in one or more tissue samples. Of this group, several phthalate esters (dimethyl phthalate, diethyl phthalate, butylbenzyl phthalate) and volatile compounds (toluene and fluorotrichloromethane) were detected in only a few samples at very low concentrations and were therefore not subjected to detailed analyses. The following 11 organic compounds were detected at sufficient frequencies and concentration to be subjected to statistical evaluation: tetrachloroethene, ethylbenzene, hexachlorobenzene, 1,3-dichlorobenzene, hexachlorobutadiene, naphthalene, bis(2-ethylhexyl) phthalate, di-n-butyl phthalate, di-n-octyl phthalate, DDE, and total PCBs.

Muscle tissue concentrations of the most commonly detected organic compounds in English sole are presented in Table 3.39. Average concentrations of organic compounds by study area (i.e., waterways, Ruston-Pt. Defiance Shoreline and Carr Inlet) are presented in Figures 3.61-3.67. Statistical analyses of muscle tissue data indicated that only four compounds had significant differences ($P<0.05$) in Commencement Bay study areas when compared to the Carr Inlet reference area: naphthalene, bis(2-ethylhexyl) phthalate, di-n-butyl phthalate, and total PCBs. Concentrations of organic compounds in English sole muscle tissue are compared by study area in the following paragraphs.

Although several low molecular weight chlorinated compounds were detected in fish muscle tissue, most of these compounds displayed very discontinuous distributions, with only a few detected values. Hexachlorobenzene and hexachlorobutadiene were detected in only two fish from Station HY-72 in Hylebos Waterway. In both cases, these compounds were detected near or below the normal detection limit. The mean concentrations of hexachlorobutadiene and hexachlorobenzene in Hylebos Waterway were very similar to those in other Commencement Bay locations or in the reference area (Figure 3.61). It should be noted, however, that the mean concentrations are based on the analytical detection limits. The actual levels of these two compounds in those areas may have been considerably less than the detection limits.

Tetrachloroethene was detected in all four areas sampled for volatile organic compounds (Figure 3.62). Highest muscle tissue concentrations (mean of 80 ug/kg wet weight) were measured in Hylebos Waterway, where this compound was detected in seven of the eight English sole sampled. Lower tissue concentrations of tetrachloroethene were measured in St. Paul and City Waterways. Although concentrations of this compound were over an order of magnitude greater in Hylebos Waterway than in Carr Inlet, there were no statistically significant differences among areas because of relatively high variability and low sample sizes (i.e., only four fish per area for volatile compounds).

Ethylbenzene, another volatile compound, showed a similar distribution in that it was detected in six of the eight English sole sampled in Hylebos Waterway. However, the mean concentration of ethylbenzene in Hylebos Waterway English sole was only 17 ug/kg wet weight. Lower tissue concentrations were measured in English sole from City and St. Paul Waterways. Ethylbenzene

TABLE 3.39. CONCENTRATIONS (ug/kg wet weight) OF ORGANIC COMPOUNDS IN ENGLISH SOLE MUSCLE TISSUE AT ALL 17 TRAWL TRANSECTS

Trawl Transect	1,3-Dichloro benzene	Naphthalene	Total PCB	Di-n-butyl Phthalate	Bis(2-ethylhexyl) Phthalate
CR70	U 20[a]	U 10	<40[b,c] U 20-60[d]	U 10 -	<60 U 10-Z260[e]
CR71	U 20 -	<98 U 10-320	<32 U 20-40	<32 U 10-120	U 10 -
HY70	U 20 -	U 10 -	536 70-1,300	1,584 720-2,500	<52 U 10-220
HY71	U 20 -	U 10 -	300 60-500	3,120 1,600-4,000	<42 U 10-170
HY72	U 20 -	<88 U 10-160	159 65-310	<22 U 10-70	U 10 -
BL70	U 20 -	<30 U 10-110	<276 U 20-580	<1,035 U 10-3,200	394 190-690
BL71	U 20 -	<27 U 10-95	236 130-490	128 10-600	334 190-460
BL72	U 20 -	U 10 -	248 130-400	U 10 -	541 265-810
SI70	<66 U 20-250	<18 U 10-84	172 50-540	U 10 -	U 10 -
MI70	U 20 -	<1,364 U 10-2,100	100 30-200	<70 U 10-310	182 100-220
SP70	U 20 -	U 10 -	40 20-70	U 10 -	U 10 -
MD70	U 20 -	U 10 -	170 40-270	U 10 -	U 10 -
CI70	<54 U 20-190	<64 U 10-210	470 160-670	U 10 -	<482 U 10-980
CI72	<134 U 20-530	<381 U 10-1,800	238 90-540	U 10 -	70 10-310
RS70	U 24 U 20-U 40	U 10 -	107 30-220	332 U 10-1,300	<508 U 10-2,100
RS71	U 20 -	U 10 -	58 30-100	U 10 -	<30 U 10-110
RS72	U 20 -	U 10 -	40 20-80	U 10 -	<228 U 10-1,100

[a] U = Undetected at the detection limit shown.

[b] < = Undetected in at least one sample. Detection limit used to calculate mean.

[c] Mean concentration.

[d] Range.

[e] Z = Value corrected for blank contributions.

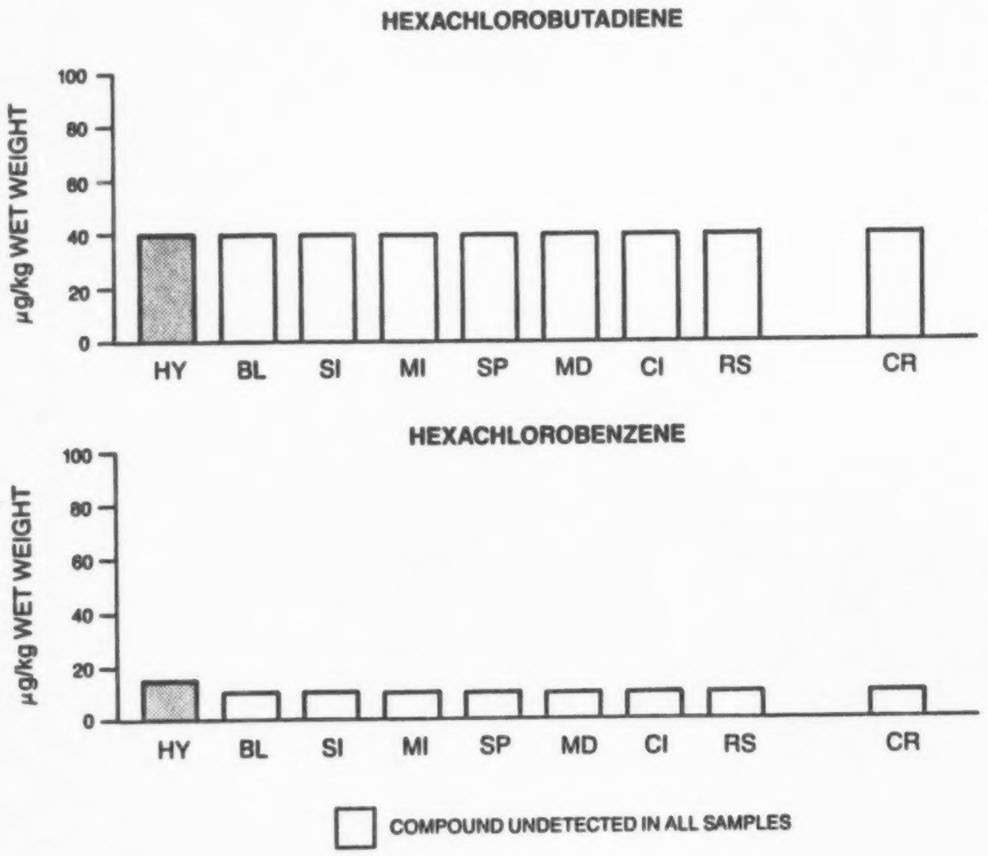


Figure 3.61. Concentrations of hexachlorobutadiene and hexachlorobenzene in English sole muscle tissue.

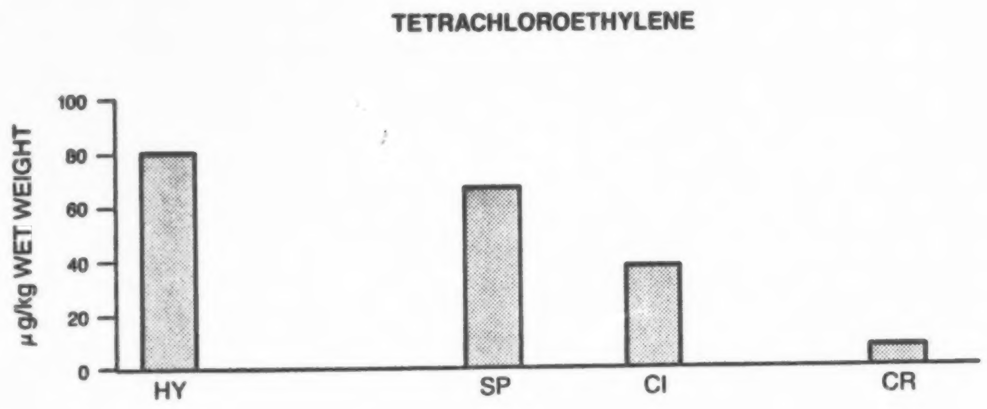


Figure 3.62. Concentrations of tetrachloroethylene in English sole muscle tissue.

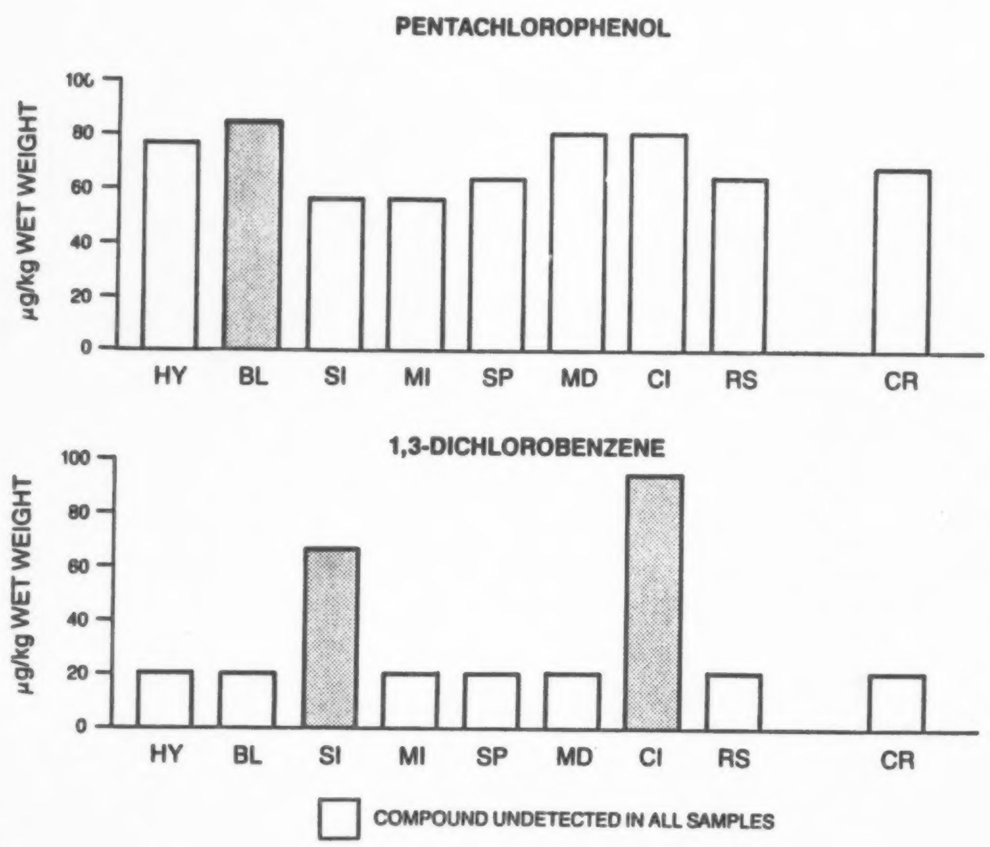


Figure 3.63. Concentrations of pentachlorophenol and 1,3-dichlorobenzene in English sole muscle tissue.

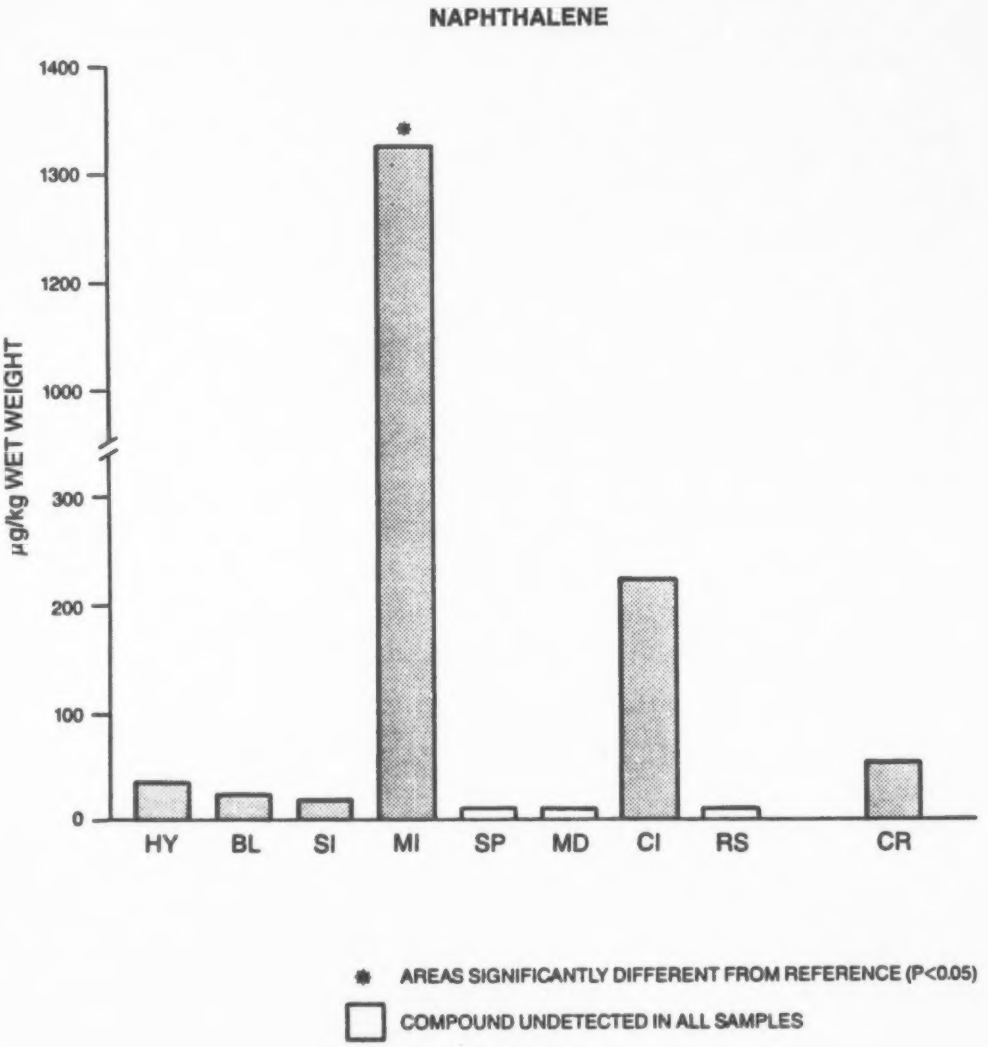


Figure 3.64. Concentrations of naphthalene in English sole muscle tissue.

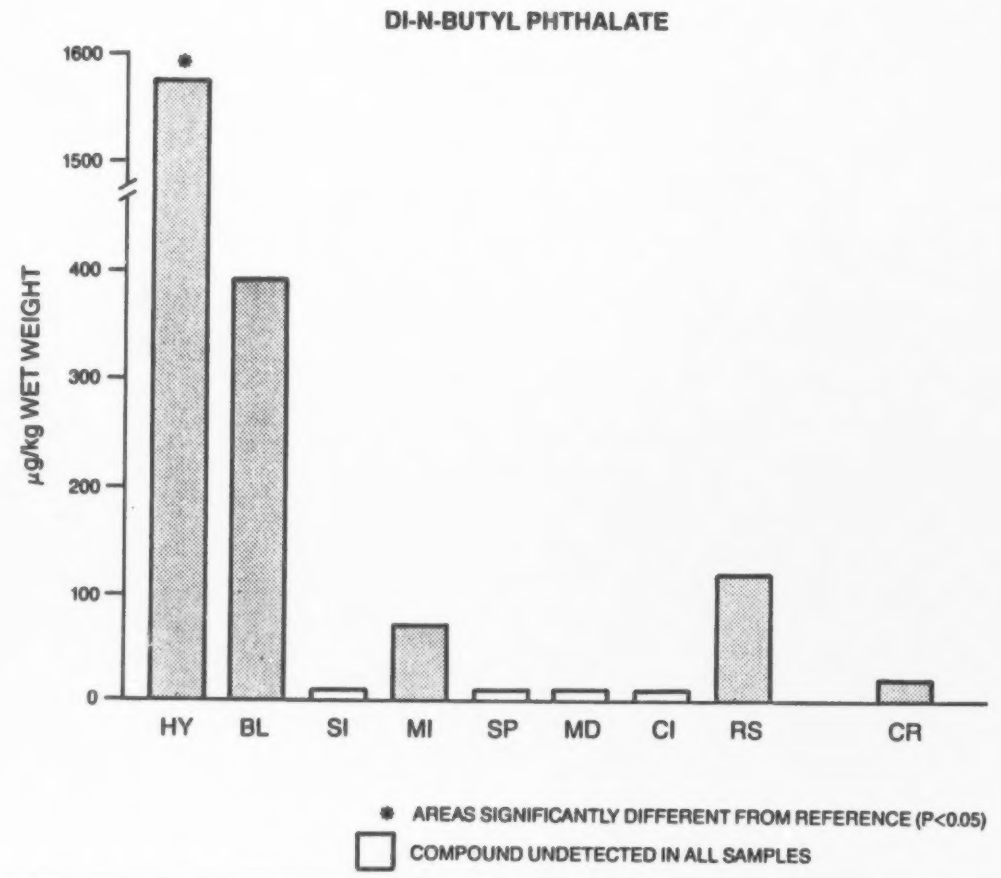


Figure 3.65. Concentrations of di-n-butyl phthalate in English sole muscle tissue.

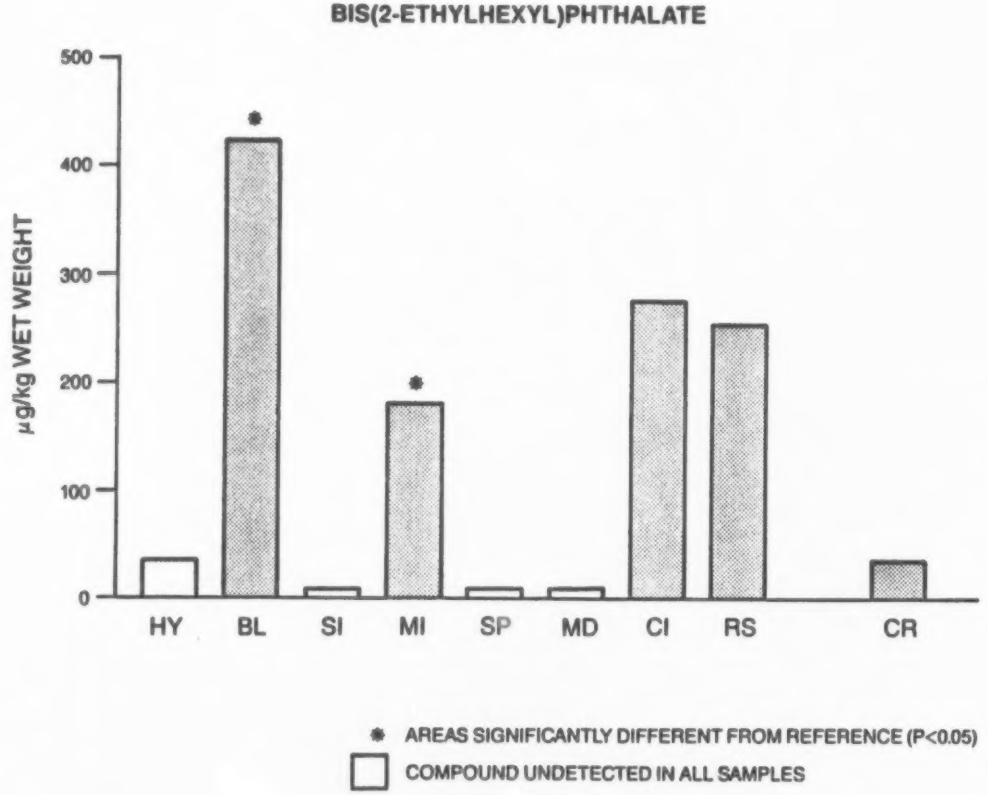


Figure 3.66. Concentrations of bis(2-ethylhexyl) phthalate in English sole muscle tissue.

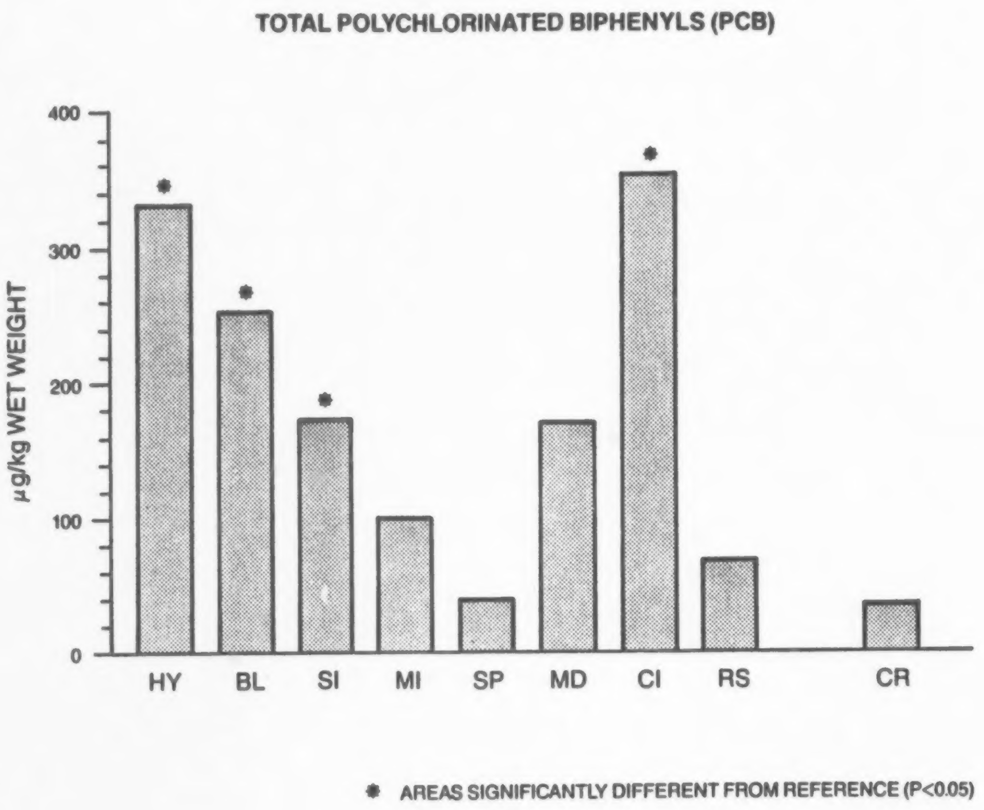


Figure 3.67. Concentrations of total PCBs in English sole muscle tissue.

was not detected in English sole from Carr Inlet at a detection limit of 5 ug/kg wet weight.

1,3-Dichlorobenzene was detected only in fish from City and Sitcum Waterways. Although this compound occurred at concentrations up to 530 ug/kg wet weight in City Waterway, its detection was limited to 3 of 10 fish in that area. Thus, the average tissue concentration in City Waterway was only about five times the reference value (Figure 3.63).

Pentachlorophenol was detected in only one fish from Blair Waterway at a concentration of 480 ug/kg wet weight. In all other samples, detection limits ranged from 40 to 80 ug/kg wet weight.

Naphthalene was the only aromatic hydrocarbon detected in English sole muscle tissue. Detection limits for aromatic hydrocarbons were typically 10 ug/kg wet weight. Naphthalene was not detected in English sole muscle samples from Ruston-Pt. Defiance Shoreline, St. Paul Waterway, or Middle Waterway. Relatively low average tissue concentrations (<50 ug/kg wet weight) were measured in Hylebos, Blair, and Sitcum Waterways, and in Carr Inlet. Most of the fish from these areas had no detected naphthalene, with occasional fish having measured concentrations of 100-300 ug/kg wet weight.

The highest average naphthalene concentration (1,300 ug/kg wet weight) was measured in English sole from Milwaukee Waterway (Figure 3.64). Four of the five fish from this waterway had naphthalene concentrations of 1,000-2,100 ug/kg wet weight. Statistical analyses revealed that the Milwaukee Waterway sole had significantly ($P<0.05$) elevated naphthalene levels when compared with Carr Inlet samples. None of the other study areas were significantly ($P>0.05$) different from Carr Inlet.

The average naphthalene concentration in English sole from City Waterway was 220 ug/kg wet weight. These sample results are not statistically significant because only 2 of the 10 fish sampled displayed elevated naphthalene concentrations (>75 ug/kg wet weight). Naphthalene was undetected in 4 of the 10 fish from City Waterway.

No pesticides were detected using GC/MS in fish muscle tissue samples from the study areas (Table 3.38). GC/MS detection limits for pesticides were typically 50 ug/kg wet weight.

Because of previously documented pesticide contamination of sediments and organism tissues in Commencement Bay, fish muscle samples were also analyzed by GC/EC to measure pesticide concentrations at lower detection limits, typically ranging from 0.8 to 12 ug/kg wet weight. Pesticides analyzed by GC/EC included: p,p'-DDE, p,p'-DDD, p,p'-DDT, hexachlorocyclohexane (lindane), aldrin, and dieldrin.

Of the six pesticides analyzed by GC/EC, only DDE was detected in any of the English sole muscle samples. Average DDE concentrations in Commencement Bay study areas ranged from 3.0 to 11.2 ug/kg wet weight (Table 3.40). Highest concentrations were measured in fish from Hylebos and City Waterways, with maximum values of 30 and 24 ug/kg wet weight, respectively. Although the tissue concentrations of DDE were relatively low throughout

TABLE 3.40. CONCENTRATIONS OF p,p'-DDE IN ENGLISH SOLE MUSCLE TISSUE

Area	Concentration (ug/kg wet weight) Mean	Range
Carr Inlet	<1.8	U 0.8-3.9[a]
Hylebos Waterway	<6.8[b]	0.9-30
Blair Waterway	9.2[b]	1.0-18
Sitcum Waterway	6.0	1.6-16
Milwaukee Waterway	6.1	1.9-12
St. Paul Waterway	<3.0	1.0-U 8.0
Middle Waterway	3.1	1.3-4.2
City Waterway	11.2[b]	1.7-24
Ruston-Pt. Defiance Shoreline	<5.3	U 1.0-19

[a] U = Undetected at detection limit indicated.

[b] Significantly different from Carr Inlet, $P<0.05$ experimentwise error rate.

the study area, statistical analyses revealed significant elevations ($P<0.05$) in Hylebos, Blair, and City Waterways. Four of the Hylebos tissue samples had relatively high DDE detection limits of 8.0 ug/kg wet weight. Removal of these values from the Hylebos sample reduced the mean DDE concentration to 6.4 ug/kg wet weight and eliminated the statistical significance for Hylebos Waterway.

All six phthalate esters were detected in one or more of the English sole muscle tissue samples. Concentrations of four phthalates (di-n-octyl, dimethyl, diethyl, and butyl benzyl) were relatively homogeneous among sampling sites, and none of the Commencement Bay areas were significantly ($P>0.05$) different from Carr Inlet.

The remaining two phthalates [di-n-butyl and bis(2-ethylhexyl)] displayed statistically significant ($P<0.05$) differences among sampling sites, but their occurrences were highly dissimilar. Di-n-butyl phthalate was detected in fish from Hylebos, Blair, and Milwaukee Waterways, the Ruston-Pt. Defiance Shoreline, and Carr Inlet (Figure 3.65). Of these areas, only Hylebos Waterway (mean concentration of 1,575 ug/kg wet weight) was significantly ($P<0.05$) different from Carr Inlet. However, some fish from both Hylebos and Blair Waterways contained relatively high concentrations of this compound (maximum of 4,000 ug/kg wet weight). Di-n-butyl phthalate was also most prevalent in Hylebos Waterway, where it was detected in 11 of the 15 English sole sampled. The average concentration in Blair Waterway English sole muscle tissue was less than that in Hylebos Waterway, and it was detected in only 4 of 15 fish.

Bis(2-ethylhexyl) phthalate was detected in Blair, Milwaukee, and City Waterways, the Ruston-Pt. Defiance Shoreline, and Carr Inlet (Figure 3.66). This compound was noticeably absent in fish from Hylebos Waterway. Statistical analyses indicated that fish from Blair and Milwaukee Waterways had significantly elevated muscle tissue concentrations when compared with those from Carr Inlet. Highest concentrations of bis(2-ethylhexyl) phthalate were measured in Blair Waterway (mean of 423 ug/kg wet weight), where all 15 fish sampled had detectable levels. The compound was detected less frequently in the other areas.

Polychlorinated biphenyls (PCBs) were the most frequently detected organic compound in samples of English sole muscle tissue. At a detection limit of 20 ug/kg wet weight, 81 of the 85 fish analyzed had detectable levels of PCBs. The prevalence of these compounds also enabled clear statistical separation of study areas based on fish muscle concentrations.

PCBs were detected at relatively low levels (30-60 ug/kg wet weight) in 7 of the 10 English sole from Carr Inlet. For the remaining three fish from Carr Inlet, PCBs were undetected at 20 ug/kg wet weight. Statistical comparisons of Carr Inlet with Commencement Bay areas indicated that sole from Hylebos, Blair, Sitcum, and City Waterways had significantly elevated muscle concentrations of PCBs (Figure 3.67). Evaluation of geographic trends indicated that highest PCB concentrations occurred in sole from Hylebos and City Waterways. Lowest levels were measured in intermediate areas, especially Milwaukee and St. Paul Waterways. Fish collected along the Ruston-Pt. Defiance Shoreline also had relatively low PCB levels.

English sole from Hylebos Waterway had an overall average PCB concentration of 332 ug/kg wet weight. This tissue level is approximately an order of magnitude higher than that measured in Carr Inlet. There was considerable variability, however, in PCB concentrations among English sole from Hylebos Waterway (range of 60-1,300 ug/kg wet weight). The maximum PCB level for Hylebos Waterway fish was also the highest concentration observed for the study. Moreover, no other fish muscle samples contained more than 800 ug/kg wet weight of PCBs.

Within Hylebos Waterway, there appeared to be a gradient of declining PCB concentrations in English sole from the waterway head to the mouth. This apparent gradient was not statistically distinguishable, however. It should also be noted that even at the uppermost Hylebos trawl site (HY70), two of the five fish had muscle PCB concentrations of less than 100 ug/kg wet weight.

English sole from City Waterway were more consistently elevated in muscle PCB concentrations than those from Hylebos Waterway. The average concentration in City Waterway samples was 354 ug/kg wet weight, with 9 of the 10 fish exceeding 150 ug/kg wet weight. English sole collected near the head of City Waterway (CI70) also had higher PCB levels than sole collected near the waterway mouth (Trawl Transect CI72).

English sole collected near the Old Tacoma fishing pier (Trawl Transect RS70) had PCB levels of 30-220 ug/kg wet weight. PCB concentrations in fish muscle tissue appeared to decline with proximity to Pt. Defiance. PCB concentrations in English sole collected from the Pt. Defiance trawl transect (RS72) were only 20-80 ug/kg wet weight, and were indistinguishable from the tissue levels measured in Carr Inlet.

Hydrophobic organic compounds such as PCBs tend to be associated with the lipid fractions of organism tissues. Measured tissue concentrations of organic contaminants can therefore be highly influenced by the amount of lipid material in the sample. To evaluate whether or not observed differences in tissue contaminant levels resulted from differences in lipid content, the fish tissue data were re-evaluated based on the lipid content, as measured by total extractable organic material. Overall, concentrations of extractable organic material in English sole muscle ranged from 1.0 to 6.5 percent (Table 3.41). Average concentrations were relatively consistent among study areas, however, and ranged from 2.1 to 3.1 percent. None of the English sole muscle samples from Commencement Bay had significantly different (P>0.05) lipid levels than samples from Carr Inlet.

To further evaluate the influence of lipids on organic priority pollutant levels, the individual pollutant concentrations for each sample were normalized to the mass of extractable organic materials. Lipid-normalized concentrations were then subjected to statistical analyses to evaluate differences among study areas. These analyses showed overall patterns similar to those resulting from analyses of uncorrected concentrations, although several noticeable differences existed. Reanalysis of the lipid-normalized data did not reveal a statistically significant (P>0.05) increase in naphthalene concentrations in English sole from Milwaukee Waterway, although the elevations above reference for non-lipid-normalized (24 times) and lipid-normalized (26 times) naphthalene levels were similar. As was the case for non-normalized

TABLE 3.41. TOTAL EXTRACTABLE ORGANIC MATERIAL IN ENGLISH SOLE MUSCLE TISSUE

Area	Total Extractable Organic Material (percent)	
	Mean	Range
Hylebos Waterway	3.0	2.2-6.5
Blair Waterway	2.3	1.5-3.7
Sitcum Waterway	3.1	2.2-4.1
Milwaukee Waterway	2.6	2.4-2.8
St. Paul Waterway	2.4	1.4-3.2
Middle Waterway	2.5	1.9-3.2
City Waterway	2.1	1.0-2.8
Ruston-Pt. Defiance Shoreline	3.2	1.9-5.7
Carr Inlet	2.5	1.9-3.8

data, naphthalene levels in four of the five English sole from Milwaukee Waterway considerably exceeded the range of concentrations measured at Carr Inlet. Therefore, the lipid-normalized naphthalene data suggest considerably elevated levels in Milwaukee Waterway fish. The lack of statistical significance results from the relatively low sensitivity of the nonparametric Mann-Whitney U-test to detect differences when the number of tied values is decreased (as was the case for lipid-normalized data).

Statistical analysis of both lipid-normalized and non-lipid-normalized data for PCBs and bis(2-ethylhexyl) phthalate indicated some differences between the two data sets. The differences in PCB concentrations between samples from Sitcum Waterway and Carr Inlet were only marginally significant in the non-normalized results, but not significant in the lipid-normalized results. Therefore, the apparent elevation in PCB levels may result from the high lipid content of Sitcum Waterway fish. PCB levels in English sole from Hylebos, Blair, and City Waterways were significantly elevated relative to Carr Inlet samples for both data sets. Fish from Milwaukee Waterway did not display significantly ($P>0.05$) elevated lipid-normalized levels of bis(2-ethylhexyl) phthalate. However, English sole from City Waterway had statistically higher concentrations of lipid-normalized bis(2-ethylhexyl) phthalate than did reference fish. This difference was not detected in analysis of non-lipid-normalized data. In summary, analyses of lipid-normalized tissue contaminant data revealed only one case [bis(2ethylhexyl) phthalate] in which a statistically significant ($P<0.05$) elevation relative to the reference value was observed that was not also detected in the non-normalized data. The significant PCB elevations for both nornalized and non-normalized data in fish from Hylebos, Blair, and City Waterways indicates that these elevations are not due to sampling of fish with higher lipid contents.

Ages of English sole used for bioaccumulation studies ranged from 3 to 10 yr. Because of the variability in fish age, an evaluation was conducted to determine whether differences in tissue contaminant levels among areas would result from differences in the age composition of English sole samples.

The age composition of the English sole samples by area is presented in Table 3.42. The mean age of English sole samples was relatively consistent among study areas, and ranged from 5.0 to 6.3 yr. Overall, English sole used for tissue analyses ranged from 3 to 10 yr of age. Analysis of variance of these data indicated no significant ($P=0.549$) differences among the mean ages of English sole from the study areas identified in Table 3.42. It is especially important to note that the mean age of the Carr Inlet reference sample (5.7 yr) was very similar to the overall mean age (5.5 yr). Therefore, there is no evidence that the observed differences in tissue contaminant levels in English sole resulted from different age composition of the samples.

3.6.5 Organic Compounds in Crab Muscle

Only six organic compounds were detected in samples of crab muscle tissue. The detected compounds included two low molecular weight aromatic hydrocarbons (phenanthrene and naphthalene), one high molecular weight aromatic hydrocarbon (fluoranthene), three phthalate esters [bis(2-ethylhexyl),

TABLE 3.42. AGE COMPOSITION OF ENGLISH SOLE SAMPLES USED FOR BIOACCUMULATION ANALYSES

Study Area	Mean Age	Range
Hylebos Waterway	5.1	3-7
Blair Waterway	6.3	4-10
Sitcum Waterway	5.6	4-7
Milwaukee Waterway	5.0	4-6
St. Paul Waterway	5.2	4-6
Middle Waterway	5.3	3-7
City Waterway	5.0	4-8
Ruston-Pt. Defiance Shoreline	5.5	3-8
Carr Inlet	5.7	3-8
All areas	5.5	3-10

di-n-butyl, and di-n-octyl phthalates], and PCBs. Phenanthrene and fluoranthene were detected only in Middle Waterway crabs at low concentrations (29 and 48 ug/kg wet weight, respectively) and will not be discussed further. Similarly, di-n-octyl phthalate was detected at low levels in Carr Inlet crab samples only. Average concentrations of the remaining phthalate esters, naphthalene, and PCBs are presented in Table 3.43.

In crab muscle samples, highest concentrations of naphthalene (1,200 ug/kg wet weight) were measured in Milwaukee Waterway, a pattern similar to that in English sole. However, naphthalene was only detected in one of the five crabs analyzed from Milwaukee Waterway.

Bis(2-ethylhexyl) phthalate and di-n-butyl phthalate were both detected at relatively high concentrations in the Carr Inlet crab samples (Table 3.43). The only possible evidence of elevated phthalate levels in crab tissue is for di-n-butyl phthalate in Hylebos Waterway. The presence of high levels of this compound in Hylebos Waterway is consistent with the English sole data.

PCBs were detected in crab tissue samples from all study areas except for a single crab sample from Hylebos Waterway. However, it should be noted that the analytical detection limits were unusually high (120 ug/kg wet weight) for the single Hylebos crab sample. Maximum PCB concentrations in crabs were generally less than those measured in English sole. Average PCB concentrations in waterway crabs ranged from 1 to 10 times Carr Inlet values. Highest overall concentrations (mean of 232 ug/kg wet weight) were measured in crabs from Sitcum Waterway. These samples were from four large Dungeness crabs (of legal size for recreational catch) collected near the head of the waterway. Because most of the other crabs collected in the waterways were considerably smaller, the PCB concentrations in the Sitcum Waterway crabs may be more representative of the range of PCB levels in edible-size crabs.

3.6.6 Comparison with Other Studies

The only other major bioaccumulation study in Commencement Bay fishes was done by Gahler et al. (1982). This study involved the collection of 92 fish and crab muscle tissue samples from four Commencement Bay locations (i.e., Hylebos Waterway, City Waterway, Old Town Dock, and Pt. Defiance Dock) and a reference site at Discovery Bay. Samples were analyzed for the full suite of U.S. EPA priority pollutants. Test species varied among sampling sites and included English sole, walleye pollock, greenling, Pacific hake, Pacific cod, and several other flatfish. English sole were consistently sampled by Gahler et al. (1982) at all five sites and can be directly compared to the results of this study.

Evaluation of the Gahler et al. (1982) data indicates that tissue levels of contaminants in English sole muscle were generally two to three higher than contaminant levels in other species. Therefore, English sole serve as a conservative model for potential bioaccumulation in other Commencement Bay species and enable consistent comparisons among areas. Concentrations of inorganic substances reported by Gahler et al.(1982) in English sole muscle tissue are presented in Table 3.44. In general, only chromium and nickel displayed tissue concentrations consistently greater than two times

TABLE 3.43. CONCENTRATIONS (ug/kg wet weight) OF SELECTED ORGANIC COMPOUNDS IN CRAB MUSCLE TISSUE

Area	Naphthalene	Bis(2-ethylhexyl) Phthalate	Di-n-butyl Phthalate	Total PCBs
Carr Inlet	U[a] 10	<1,331[b,c] U 10-9,100[d]	<540 U 10-1,300	U 22 U 20-U 30
Hylebos Waterway	U 10 -	U 10 -	2,900 -	120 -
Blair Waterway	U 10 -	U 10 -	U 10 -	130 -
Sitcum Waterway	<20 U 10-25	U 10 -	U 10 -	232 60-480
Milwaukee Waterway	<248 U 10-1,200	28 U 10-100	U 10 -	74 30-130
St. Paul Waterway	U 10 -	U 10 -	U 10 -	U 20 -
Middle Waterway	U 10 -	U 10 -	U 10 -	40 30-50
City Waterway	U 10 -	60 U 10-260	46 U 10-190	66 30-110

[a] U = Undetected at detection limit shown.

[b] < = Undetected in at least one sample. Detection limit used to calculate mean.

[c] Mean.

[d] Range.

TABLE 3.44. CONCENTRATIONS (mg/kg wet weight) OF METALS IN COMMENCEMENT BAY ENGLISH SOLE MUSCLE TISSUE AS DETERMINED BY GAHLER ET AL. (1982)

		As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
Hylebos	Median	4.1	0.008	0.15	0.26	0.21	0.03	1.2	5.0
n=5	Mean	4.9	0.008	0.23	0.28	0.25	0.03	1.3	5.1
	Maximum	7.3	0.011	0.62	0.31	0.36	0.04	1.4	5.6
City	Median	4.5	<0.005	0.24	0.27	0.32	0.03	0.52	5.0
n=5	Mean	5.1	<0.005	0.31	0.32	0.32	0.04	0.65	5.5
	Maximum	8.6	<0.005	0.64	0.50	0.45	0.09	1.2	7.7
Old Town	Median	3.2	0.006	0.13	0.40	0.55	0.02	0.45	6.0
Dock	Mean	2.9	0.007	0.14	0.38	0.58	0.03	0.46	5.9
n=3	Maximum	3.4	0.008	0.15	0.40	0.69	0.04	0.48	6.3
Pt. Defiance	Median	7.9	0.004	0.22	0.42	0.72	0.03	0.43	7.0
Dock	Mean	8.6	0.007	0.28	0.39	3.9	0.03	0.52	6.5
n=3	Maximum	14.6	0.012	0.41	0.49	10.4	0.03	0.73	7.3
Discovery	Median	3.6	0.006	0.07	0.40	0.46	0.04	0.17	4.7
Bay	Mean	3.2	<0.006	0.06	0.42	0.46	0.04	0.23	5.2
n=3	Maximum	4.1	0.008	0.07	0.44	0.61	0.05	0.33	7.0

the reference values. Arsenic was elevated in bottomfishes from the Pt. Defiance Dock (2.7-4.0 times reference concentrations), but did not display substantial elevations at the other sites. Gahler et al. (1982) also collected limited samples of Dungeness crab muscle tissue from the study area. Chromium, copper, and lead were elevated about two to five times reference concentrations, suggesting increased bioaccumulation of these metals in Hylebos and City Waterways.

The possible low-level elevations of chromium, copper, and arsenic at Commencement Bay sites sampled by Gahler et al. (1982) are not substantiated by the results of the present study. Average arsenic levels in English sole from the Ruston-Pt. Defiance Shoreline area (6.3 mg/kg wet weight) were slightly less than those detected by Gahler et al. (1982) (8.6 mg/kg wet weight). However, the ranges of values for both studies are similar, and the combined results indicate no significant elevations in tissue arsenic levels in fishes from Commencement Bay.

The Gahler et al. (1982) results indicate that chromium and nickel tissue concentrations were about two to six times higher in some Commencement Bay sites relative to Discovery Bay. These apparent elevations are not supported by the results of the present study. Chromium and nickel concentrations in English sole muscle were very consistent among sampling areas. Since the Gahler et al. (1982) results indicate only relatively minor elevations of these metals, it is concluded that chromium and nickel are not elevated in Commencement Bay fishes.

The organic pollutant bioaccumulation results of Gahler et al. (1982) are similar to the results of this study in that relatively few contaminants were consistently detected in fish muscle tissue. Compounds detected consistently included PCBs, phthalates, and DDT residues. Similarities between the results of Gahler et al. (1982) and this study include:

- Hexachlorobenzene and chlorinated ethylenes were detected only in Hylebos Waterway fishes.

- Highest PCB levels with similar maximum values were measured in fish from City and Hylebos Waterways (Table 3.45).

- DDT residues were measured in low concentrations throughout the study area.

- Phthalates were detected at several locations in the study area.

- There was no evidence of excess accumulation of hexachlorobutadiene in fish muscle.

Major differences between the two studies include the detection by Gahler et al. (1982) of higher hexachlorobenzene levels (up to 150 ug/kg wet weight) in English sole from Hylebos Waterway. Gahler et al. (1982) also detected low levels of DDT, DDE, and DDD in fish muscle, whereas this study detected only the DDE form of the pesticide.

TABLE 3.45. CONCENTRATIONS (ug/kg wet weight) OF PCBs AND HEXACHLOROBENZENE IN FISH MUSCLE TISSUE IN HYLEBOS AND CITY WATERWAYS AS DETERMINED BY GAHLER ET AL. (1982)

Area	Fish Species	PCB		HCB	
		Mean	Range	Mean	Range
Hylebos Waterway	Whitespotted greenling	860	540-1,120	59	14-96
	English sole	550	130-1,030	110	56-150
	Pacific staghorn sculpin	260	170-340	31	28-34
City Waterway	English sole	190	54-360	U[a] 1	-
	Walleye pollock	170	17-530	U 1	-
	Pacific cod	37	36-38	U 1	-
Old Town Dock	English sole	120	91-160	U 1	-
	Pacific hake	93	50-140	U 1	-
	Walleye pollock	24	17-33	U 1	-
Pt. Defiance Dock	English sole	330	100-640	U 1	-
	Walleye pollock	58	17-130	U 1	-
	Pacific staghorn sculpin	49	45-52	U 1	-

U = Undetected at detection limit shown.

Gahler et al. (1982) measured higher PCB levels in English sole from the Ruston-Pt. Defiance Shoreline than were measured in this study. For the samples collected in 1981, the muscle tissue concentrations of PCBs in English sole from the Ruston-Pt. Defiance area ranged from 91 to 640 ug/kg wet weight. For the present study, English sole collected in the same area in 1984 had PCB levels of 20 to 100 ug/kg wet weight. The reasons for these apparent differences are unknown.

Malins et al. (1982) reported PCB concentrations ranging from 160 to 850 ug/kg wet weight in English sole muscle samples from Commencement Bay. The location and time of collection of these samples were not reported by Malins et al. (1982), however. Since Malins et al. (1980, 1982) have previously collected fish from Hylebos and City Waterways, it is assumed that at least some of the five samples came from these areas and were probably collected around 1981. The PCB values reported by Malins et al. (1982) for English sole are within the range of values measured in the present study for Hylebos and City Waterways.

3.6.7 Summary

- With the exception of copper, metal concentrations in English sole muscle tissue were relatively homogeneous among study areas. For these metals there was no evidence of excessive accumulation in Commencement Bay fish when compared with those from the Carr Inlet reference area. The maximum average concentrations of most metals in Commencement Bay fish were less than 2 times the average reference concentration. Copper was significantly elevated (3-9 times reference) in fish from several areas of Commencement Bay.

- The only metals displaying elevated concentrations in Commencement Bay crabs were lead and mercury. Maximum elevations of these metals in crab muscle were about five times reference concentrations.

- There was no evidence of arsenic accumulation above reference levels in fish or crabs from Commencement Bay.

- Only 10 organic compounds were detected in more than a few fish samples from Commencement Bay.

- The only aromatic hydrocarbon detected in English sole muscle was naphthalene, which occurred at relatively high concentrations in City and Milwaukee Waterways.

- The chlorinated compounds hexachlorobenzene and hexachlorobutadiene were detected only at relatively low concentrations (about 40 ug/kg wet weight) in two of five English sole from a single Hylebos Waterway trawl.

- PCBs were detected in all fish sampled in Commencement Bay and occurred at maximum concentrations (approximately 10 times reference) in English sole from Hylebos and City Waterways.

- The only pesticide detected in Commencement Bay sole was DDE, which occurred at relatively low concentrations (generally <10 ug/kg wet weight) throughout the study area.

- PCBs were the only organic compounds consistently detected in Commencement Bay crabs. PCB concentrations in crabs were generally less than concentrations in English sole.

4.0 CONTAMINANT, TOXICITY, AND BIOLOGICAL EFFECTS RELATIONSHIPS

4.1 INTRODUCTION

Quantitative relationships among the contaminant, toxicity, and biological effects variables used in the Commencement Bay Superfund Investigation are examined in this section. In Section 5, these variables are used independently to assess environmental hazards and to prioritize study areas. The data analyses conducted in Section 4 are designed to meet two objectives:

1. To determine levels of sediment contamination above which significant toxicity or biological effects would be expected to occur

2. To identify contaminants of concern from the numerous contaminants detected at elevated concentrations in Commencement Bay sediments.

These objectives were met by evaluating whether there was increased toxicity or biological effects with increasing sediment contaminant concentrations. Both statistical and nonstatistical approaches were used to investigate these relationships. The Commencement Bay database includes sediment chemistry and biological information at sites displaying a wide range of sediment contaminant levels. Therefore, these data were used to determine threshold effect levels of contaminants or contaminant groups that could be used to evaluate potential toxicity or biological effects at sites where only sediment chemistry data were available.

For a given area (e.g., a waterway), these relationships will identify the contaminants that seem to be most responsible for any observed toxicity or biological effects. In this study, it was assumed that contaminants displaying monotonically increasing relationships with a toxic or biological effect had a higher relative priority (i.e., a higher potential for being a causative agent) than contaminants displaying no discernible relationships with effects.

This section also examines the interrelationships among some of the important toxicity and biological variables (i.e., benthic infauna vs. bioassays, and bioaccumulation vs. histopathology in English sole). The objectives of these assessments are to evaluate the relative merits of the independent biological measurements and to develop recommendations for future use of these variables.

4.2 RELATIONSHIPS AMONG CONTAMINANTS, TOXICITY, AND BENTHIC EFFECTS

This section examines the correspondence among concentrations of sediment contaminants and occurrences of significant sediment toxicity and benthic effects (defined in Sections 3.2 and 3.3). Concentrations [dry-weight (DW)] of at least one organic or inorganic contaminant were elevated above Puget Sound reference conditions in surface sediments from all Commencement Bay stations. Significant toxicity or benthic effects were observed at 29 of the 52 Commencement Bay stations where bioassays and benthic infaunal studies were conducted. Hence, elevated chemical concentrations did not always result in statistically significant effects. Sources of variability associated with contaminant-benthic infauna relationships included random variability at each benthic station. Benthic sampling was conducted synoptically with chemical sampling, but used different grab samples. This variability was a smaller factor in contaminant-toxicity relationships because bioassays were conducted on homogenized aliquots of the same sediment sample taken for chemical analysis.

Toxicity and benthic "apparent effect thresholds" (AET) for chemical contaminants are derived in this section by comparing the magnitudes of chemical contamination between three groups of sediments: 1) sediments that do not exhibit toxicity, 2) sediments that do not exhibit benthic effects, and 3) sediments that do exhibit toxicity or benthic effects. Chemicals with concentrations exceeding an AET are summarized for each station where significant toxicity or benthic effects were observed.

Because of the wide variation in chemical composition among Commencement Bay areas, it is unlikely that a single contaminant or group of contaminants was associated with all observed toxicity or benthic effects. Therefore, the spatial distributions of chemical concentrations exceeding an AET were compared with gradients of sediment toxicity and benthic responses at closely spaced stations. This comparison was used to determine which, if any, chemical concentration gradients corresponded to toxicity or effects gradients within small areas. Chemicals with concentrations that exceeded AET and correlated with toxicity or benthic effects gradients at affected sites received the highest priority for source evaluation in later sections.

4.2.1 Correlation of Indicators

Sediment toxicity was observed at 25 of 52 stations in Commencement Bay study areas, as evidenced by statistically significant mortality in the amphipod bioassay or abnormality in the oyster larvae bioassay. Significant benthic effects were observed at 18 of the 50 stations sampled for benthic infauna. Benthic effects were defined as a statistically significant depression in the abundance of one or more major taxa relative to conditions at a reference area with sediments of similar texture. Variations in the concentrations of sediment contaminants at biological stations were examined to identify correspondence between contaminant concentrations and observed toxicity or benthic effects. Because sediment characteristics (i.e., total organic carbon, percent fine-grained material) may influence the toxic response of organisms to a contaminant, relationships among sediment contamination, sediment toxicity, and benthic effects were evaluated using contaminant concentrations normalized alternatively to sediment dry weight, total organic carbon, and percent fine-grained material.

Where synoptic biological and chemical data were collected, significant toxicity in both bioassays as well as benthic effects were observed at all but one station where the dry-weight concentration of at least one metal or organic compound exceeded 1,000 times reference conditions (i.e., chemicals listed in Table 3.12 in Section 3.1.5.3). The exception was Station HY-43, where trichlorinated butadiene concentrations were nearly

2,000 times reference conditions, but neither bioassays nor benthic effects were significant. In other sediments where there were no significant toxic responses or benthic effects, concentrations of organic compounds (besides chlorinated butadienes) ranged from 1 to <400 times reference conditions and concentrations of metals were <50 times reference conditions.

Sediment toxicity and the number of significant benthic effects were highest in the most chemically contaminated study areas. Toxicity increased and abundances of major taxa decreased with increasing concentrations of some contaminants over the entire study area. Examples of this relationship are given in Figure 4.1. A common characteristic of these plots was considerable scatter in the magnitude of sediment toxicity and taxa abundances at lower chemical concentrations. When trends were observed, the minimum toxicity increased and the maximum abundances decreased at higher contaminant concentrations. When data from all study areas were plotted together for a given contaminant, there was no clear trend in the values of maximum toxicity or minimum abundances over the concentration range of the contaminant. This latter feature is consistent with the conclusion that no one contaminant or contaminant group correlated with the effects observed in all areas.

In some cases there was random scatter in the values up to a certain contaminant concentration. Above that concentration, there was an rapid change to uniformally high toxicity or low abundances at the few most contaminated sites. If the high contaminant levels were associated with the effects observed, the abrupt change in the scatter suggested an "effect threshold" for the contaminant. These potential "effect thresholds" are evaluated in the following section.

4.2.2 Apparent Chemical Effect Thresholds

The use of synoptic chemical, toxicity, and benthic infaunal data in predicting concentrations of contaminants (e.g., lead) above which toxicity and benthic effects would be expected is shown in Figure 4.2. Results from all 52 Commencement Bay stations with concurrent chemical, toxicity, and benthic data were used in this evaluation. Benthic infauna data were not collected for two stations along the Ruston-Pt. Defiance Shoreline (RS-22 and RS-24).

The range in lead concentrations (DW) at biological stations is shown in Figure 4.2 for three groups of sediment samples. The first group consisted of the 32 stations where no statistically significant benthic effects were observed. The lead concentration for this "no benthic effects" group ranged from 8.3 to 300 mg/kg DW. The second group consisted of the 28 stations where no statistically significant sediment toxicity was observed in bioassays. The lead concentration for this "no toxicity" group ranged from 8.3 to 660 mg/kg DW. The third group consisted of the 29 stations where either statistically significant sediment toxicity or benthic effects were observed. The lead concentration for this "affected" group of stations ranged from 11 to 6,250 mg/kg DW.

Some stations were included in more than one group. For example, significant sediment toxicity was observed at 9 of the 32 stations that exhibited no significant benthic effects. These nine stations were included in both the "no benthic effects" group and in the "affected" group. Likewise,

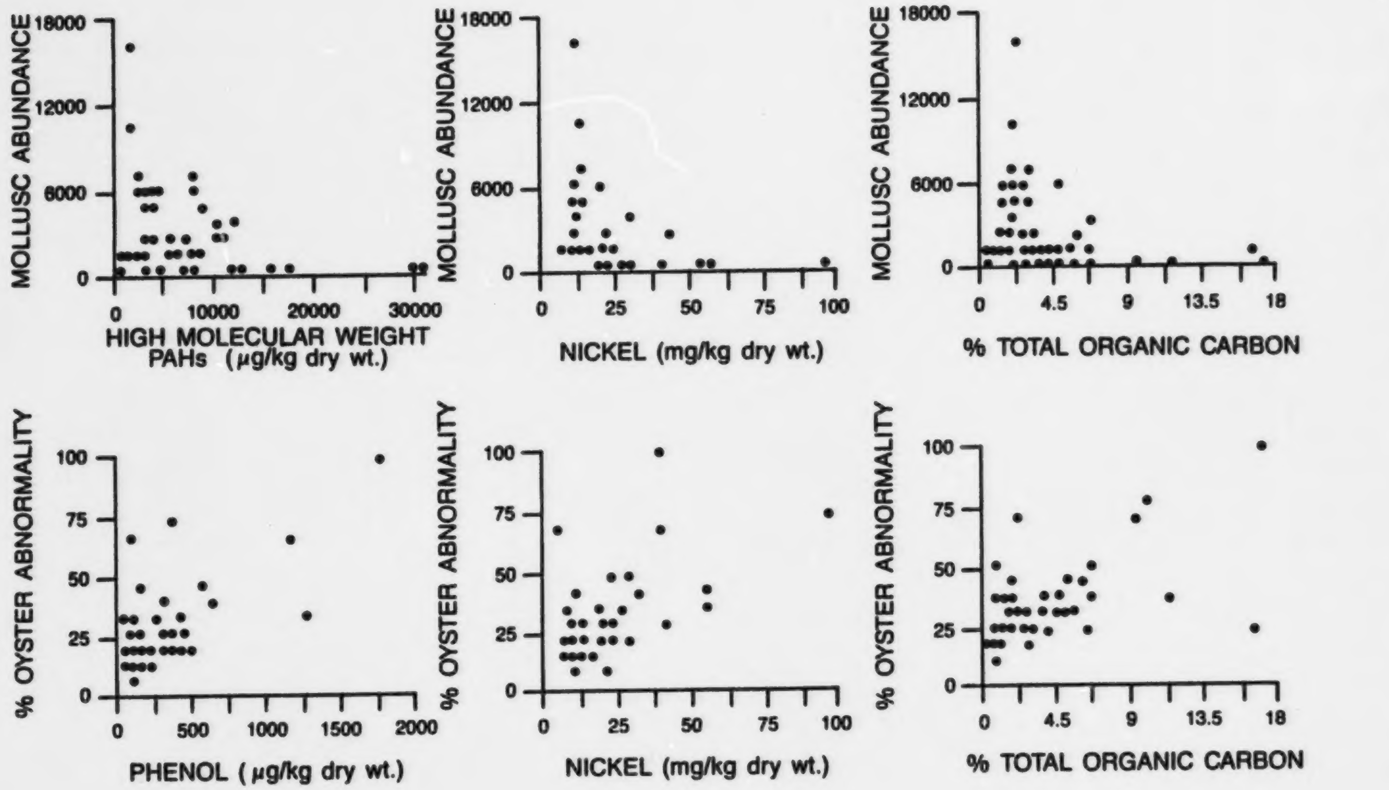


Figure 4.1. Correlation patterns among selected contaminants, sediment toxicity, and benthic effects.

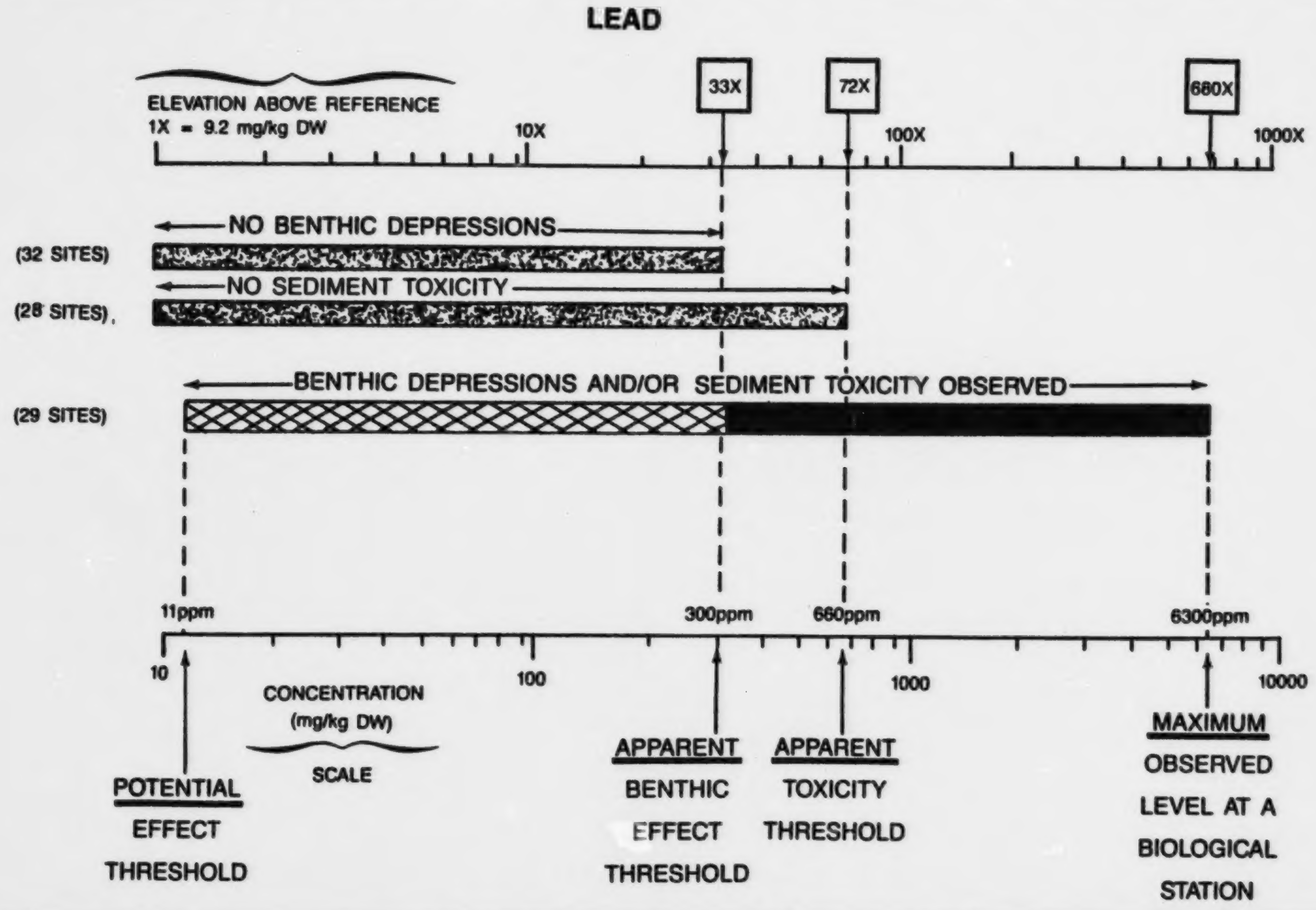

LEAD
ELEVATION ABOVE REFERENCE
1X = 9.2 mg/kg DW
10X
100X
1000X
33X
72X
660X
NO BENTHIC DEPRESSIONS
(32 SITES)
NO SEDIMENT TOXICITY
(28 SITES)
BENTHIC DEPRESSIONS AND/OR SEDIMENT TOXICITY OBSERVED
(29 SITES)
11ppm
300ppm
660ppm
6300ppm
10
100
1000
10000
CONCENTRATION
(mg/kg DW)
SCALE
POTENTIAL
EFFECT
THRESHOLD
APPARENT
BENTHIC
EFFECT
THRESHOLD
APPARENT
TOXICITY
THRESHOLD
MAXIMUM
OBSERVED
LEVEL AT A
BIOLOGICAL
STATION

Figure 4.2. Example use of synoptic benthic effects and sediment toxicity data to determine apparent chemical effect thresholds.

the 23 Commencement Bay stations where neither significant benthic effects nor sediment toxicity were observed were included in both the "no benthic effects" group and in the "no toxicity" group. The range of lead concentrations for these 23 stations was 8.3 to 300 mg/kg DW.

The concentration range of lead for the "affected" group of sediments indicated that significant sediment toxicity or benthic effects did not occur at the Commencement Bay biological stations when lead levels were below 11 mg/kg DW (EAR = 1.2). This level defined a "potential effect threshold" (i.e., higher lead concentrations may have resulted in significant sediment toxicity or benthic effects). This threshold was termed "potential" because toxicity or benthic effects were found at some, but not all, of the stations with higher lead concentrations. The toxicity or benthic effects observed at these stations could have resulted from other contaminants or conditions.

A toxicity "apparent effect threshold" (AET) was defined as the contaminant concentration above which significant sediment toxicity would always be expected (Figure 4.2). Similarly, benthic AET was defined at the contaminant concentration above which significant benthic effects would always be expected. The toxicity AET and benthic AET may or may not occur at the same concentration of a chemical. For example, significant benthic depressions were observed at all seven stations with lead concentrations greater than 300 mg/kg DW (EAR = 33). Significant sediment toxicity was also observed at all three stations with lead concentrations greater than 660 mg/kg DW (EAR = 72). These effect thresholds were termed "apparent" because significant toxicity or benthic effects were not found at some stations with equal or lower lead concentrations, while significant sediment toxicity or benthic effects were found at all stations with higher concentrations. These empirical relationships do not prove that contaminants found above an AET were responsible for the observed toxicity or benthic effects. Within the limits of this data set, chemicals present above this concentration were associated exclusively with problem sediments having significant toxicity or depressed benthic infaunal abundances (or both). Because of this association, all chemicals present above an AET were defined as problem chemicals requiring further evaluation.

Major sources of variability in determining AET include: 1) the statistical error ($P<0.05$) associated with the significance of bioassay and benthic infauna results, and 2) the analytical error associated with the quantification of chemical results. The analytical precision attained typically ranged from 5 to 50 percent (relative percent difference) depending on the chemical. The accuracy of the organic compound results was improved by use of isotope dilution mass spectroscopy to provide a minimum correction for compound recovery (see Methods Section 2.2).

The AET determined in this section do not distinguish potential synergism and other factors that may contribute to observed toxicity or benthic effects at one station but not at another. The contribution of these factors cannot be determined from the data available. With the existing data, the approach does provide a means of prioritizing the list of potential problem chemicals by giving less weight to those for which contradictory evidence was found at stations without significant toxicity or benthic effects.

The approach shown in Figure 4.2 was used to identify toxicity and benthic AET for all chemicals of concern summarized in Section 3.1 (see Tables 3.4 and 3.10), in addition to tentatively identified organic compounds detected at multiple sites (see Table 3.6). These AET expressed on a dry-weight basis are summarized for metals and organic compounds in Tables 4.1 and 4.2. Where the observed effect threshold for sediment toxicity differed from that for benthic effects, both AET are shown. Biological stations where each contaminant exceeded either AET are also identified. Corresponding AET for conventional variables (e.g., total organic carbon) are summarized in Table 4.3.

One or more metals exceeded an AET in sediments from stations in Hylebos, Sitcum, and City Waterways, and along the Ruston-Pt. Defiance Shoreline. Several metals had different sediment toxicity and benthic effects thresholds. Without exception, the AET was higher for sediment toxicity than for benthic effects, suggesting that benthic effects were more sensitive to metals than were bioassay responses.

One or more organic compounds or compound groups exceeded an AET at stations in Hylebos, Sitcum, St. Paul, and City Waterways, and along the Ruston-Pt. Defiance Shoreline. AET were usually higher for benthic effects than for sediment toxicity where there were differences between these indicators. These data suggest that bioassay responses were more sensitive to organic compound contamination than were benthic effects.

Chemicals with concentrations that exceeded an AET (DW) at each of the 29 stations exhibiting a significant toxic response or benthic effect are summarized in Table 4.4. Concentrations of one or more metals exceeded these levels at 41 percent (12/29) of the affected stations. Organic compounds were found above an AET at 76 percent (22/29) of the stations. Wherever sediment toxicity and benthic effects were observed together, at least one chemical exceeded an AET (DW). Likewise, wherever both amphipod and oyster larvae biossay results were significant, some chemical exceeded an AET, even when no significant benthic effects were observed.

No chemicals exceeded an AET (DW) at 21 percent (6/29) of the stations exhibiting a significant toxic response or benthic effect. Four of these six stations were unusual in that the only effect observed was significant amphipod mortality. These four stations (B-15, BL-25, MI-11, and MI-15) were the only stations with significantly toxic sediments of all biological stations in Blair and Milwaukee Waterways. The mean amphipod mortality at these four stations ranged from 20 to 32 percent. A common characteristic among these stations was the presence of fine-grained material in excess of 80 percent (82, 88, 86, and 85 percent, respectively). Sediment contamination in both Blair and Milwaukee Waterways was relatively low compared with other Commencement Bay areas. Moreover, no significant benthic effects or oyster larvae abnormalities were observed at any biological station in either waterway. These data suggest that the amphipod bioassay may be responsive to high levels of fine-grained material in sediments in addition to chemical contamination. Ott (1985) also found that *Rhepoxinius abronius* in bioassays appear to respond negatively to high levels of fine-grained material. Alternative explanations for the patterns observed in Blair and Milwaukee Waterways include:

TABLE 4.1. APPARENT EFFECT THRESHOLDS FOR POTENTIAL PROBLEM METALS NORMALIZED TO DRY WEIGHT

METALS	APPARENT EFFECT THRESHOLD (mg/kg)	BIOLOGICAL STATIONS AND CONCENTRATIONS EXCEEDING THRESHOLD (mg/kg)	
Antimony	5.3/3.1	RS-22	5.3
		RS-24	26
		RS-19	36
		RS-18	420
Arsenic	93/85	HY-17	86
		HY-22	90
		RS-20	90
		SI-11	93
		RS-24	700
		RS-19	1,500
		RS-18	9,700
Cadmium	5.8	CI-13	6.7
		RS-24	9.6
		RS-19	16
		RS-18	180
Copper	310	RS-24	390
		RS-19	2,200
		RS-18	11,000
Lead	660/300	CI-13	450
		SI-12	500
		RS-24	530
		SI-11	660
		CI-11	720
		RS-19	1,000
		RS-18	6,300
Mercury	0.59/0.52	CI-11	0.53
		RS-20	0.59
		CI-13	1.1
		RS-19	3.2
		RS-18	52
Nickel	39	CI-11	40
		SP-14	40
		HY-22	52
		HY-23	56
		RS-18	93
Zinc	490/260	HY-17	270
		CI-11	320
		SI-12	340
		SI-11	490
		RS-19	910
		RS-18	3,300
		RS-24	1,600

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[a] Where two values are shown, the one on left is the toxicity threshold and the one on right is the benthic effects threshold. The lower of these paired values is underlined. Where only one value is shown, the two apparent thresholds are identical.

TABLE 4.2. APPARENT EFFECT THRESHOLDS FOR POTENTIAL PROBLEM ORGANIC COMPOUNDS NORMALIZED TO DRY WEIGHT

ORGANIC COMPOUNDS	APPARENT EFFECT THRESHOLD (ug/kg)	BIOLOGICAL STATIONS AND CONCENTRATIONS EXCEEDING THRESHOLD (ug/kg)	
Phenol	420/1,200	HY-12 HY-22 CI-11 CI-20 SP-14	500 530 1,100 1,200 1,700
2-Methylphenol	63/72	RS-18 RS-13	71 71
4-Methylphenol	670	SP-16 CI-16 SP-15 SP-14	890 1,200 2,600 96,000
LMW aromatic hydrocarbons	5,200	SP-14 RS-18	6,100 20,000
HMW aromatic hydrocarbons	12,000/17,000	HY-14 HY-17 HY-22 RS-18	17,000 18,000 30,000 31,000
Chlorinated benzenes	270/400	RS-18 HY-47 HY-42 CI-11 CI-16 HY-22	290 310 400 430 680 1,300
Chlorinated butadienes	47,000^{b,c}	NONE	
Total phthalates	3,400/5,200	CI-13 HY-22 HY-12	3,600 3,700 5,200
Total PCBs	420/1,100	HY-42 HY-23 HY-22	1,100 1,500 2,000
Benzyl alcohol	130	SP-16 CI-11	130 140
Dibenzofuran	540	RS-18	2,000
Aniline	U 20^{d}	CI-11	1,400
N-Nitrosodiphenylamine	28	RS-24 SI-12 CI-16 RS-18	40 130 220 610
Tetrachloroethene	140	HY-23 HY-17	170 210
Ethylbenzene	37	HY-17	50
Total xylenes	120	HY-17	160
1-Methyl-2-(1-methylethyl)benzene[e]	2,300/1,100	SP-15 SI-11 HY-17 SP-14	1,400 2,300 2,800 6,600
2-Methoxyphenol[e]	930	SP-15 SP-14	1,500 3,900
1,1'-Biphenyl[e]	260/270	CI-20 SP-14 RS-18	270 310 1,100
Dibenzothiophene[e]	240/250	CI-20 HY-22 RS-18	250 320 1,100
Pentachlorocycopentane[e]	72^{b,c}	NONE	
Diterpenoid hydrocarbons			
Isopimardiene[e]	1,500	SP-14	5,900
Unidentified diterpene[e,f]	2,000	SI-12 SP-14	2,100 5,200
Retene[e]	1,200/2,000	SP-16 SI-15	1,700 2,000

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[a] Where two values are shown, the one on left is the toxicity threshold and the one on right is the benthic effects threshold. The lower of these paired values is underlined. Where only one value is shown, the two apparent thresholds are identical.

[b] No apparent toxicity threshold was observed for this chemical. The value shown is the maximum concentration observed.

[c] No apparent benthic effects threshold was observed for this chemical. The value shown is the maximum concentration observed.

[d] Aniline was undetected at 20 ug/kg DW at all stations except CI-11.

[e] This compound was identified by matching the sample spectra with library reference spectra. The identification is considered tentative because standards of this compound are not routinely analyzed.

[f] Possibly kaur-16-ene.

TABLE 4.3. APPARENT EFFECT THRESHOLDS FOR CONVENTIONAL VARIABLES

PARAMETER	APPARENT EFFECT THRESHOLD[a]	BIOLOGICAL STATIONS AND CONCENTRATIONS EXCEEDING THRESHOLD	
Total volatile solids (%)	22.2	SP-14	44.7
Total organic carbon (%)	15.1	SP-14	16
Nitrogen (%)	0.28	CI-13	0.29
		CI-11	0.35
		CI-16	0.49
		SP-14	0.79
		HY-47	0.89
		SP-16	1.2
Oil and grease (mg/kg)	2,200/4,300	CI-16	3,300
		CI-13	3,400
		RS-18	4,100
		B-15	4,300
		CI-11	5,700

[a] Where two values are shown, the one on left is the toxicity threshold and the one on right is the benthic effects threshold. The lower of these paired values is underlined. Where only one value is shown, the two apparent thresholds are identical.

TABLE 4.4. SUMMARY OF EFFECTS AND POTENTIAL PROBLEM CHEMICALS AT BIOLOGICAL STATIONS (NORMALIZED TO DRY WEIGHT)

Toxicity and/or Effect[a]	Station	Chemical[b] Exceeding An Apparent Effect Threshold
O	HY-12	PNOL[c], PHTH
M	HY-14	HPAH
O M C	HY-17	LPAH, PCE, XYL, EBEN, AS[d], Zn[d], MBEN
O A M C	HY-22	PNOL[c], HPAH, PHTH[c], TPCB, CBEN, HCBD, As[d], Ni, DIB
O A M P T	HY-23	HPAH[d], TPCB, PCE, Ni
M C T	HY-32	
M	HY-37	
A	HY-42	TPCB, CBEN[c], HCBD
O M	HY-47	CBEN[c], HCBD, N
A	B-15	O & G[c]
A	BL-25	
C	SI-11	AS[d], Pb[d], Zn[d], MBEN[d]
A C	SI-12	NDPA, Pb[d], Zn[d], DTP[c]
A	SI-15	RETA[c]
A	MI-11	
A	MI-15	
O	SP-12	
O A M C P T	SP-14	4MNOL, PNOL, LPAH, Ni, MBEN, MOX, DTP, BIPH, TVS, TOC N
O A M C	SP-15	4MNOL, MBEN[b], MOX
O A T	SP-16	4MNOL, BZOH, RET[c], N
O A M	CI-11	PNOL[c], BZOH, ANIL, HPAH[d], CBEN, Hg[d], Pb, Ni, Zn[d], O&G, N, S
O M C P T	CI-13	PHTH[c], Cd, Pb[d], Hg, O&G, N, S
O M C P T	CI-16	4MNOL, CBEN, NDPA, O&G, N, S
O A	CI-20	PNOL[c], BIPH[c], DIB[c],
O A	RS-13	2MNOL[c]
O A M C P T	RS-18	2MNOL, NDPA, LPAH, HPAH, CBEN[c], BIPH, DIB, DBF, Sb, As, Cd, Cu, Pb, Ah, Ni, Zn
O A M	RS-19	Sb, As, Cd, Cu, Pb, Hg, Zn
M	RS-20	As[d], Hg[d]
A[e]	RS-24	NDPA, Sb, As, Cd, Cu, Pb[d], Zn

TABLE 4.4. (Continued)

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[a] O = oyster abnormality
A = amphipod mortality
M = mollusc abundance
C = crustacean abundance
P = polychaete abundance
T = total benthic abundance

[b] PNOL = phenol
HPAH = high molecular weight aromatic hydrocarbons
PCE = tetrachloroethene
XYL = total xylenes
EBEN = ethylbenzene
MBEN = 1-methyl-2-(methylethyl)benzene
PHTH = total phthalates
TPCB = total PCBs
CBEN = total chlorinated benzenes
HCBD = hexachlorobutadiene
MPYR = methylpyrene
MPHEN = methylphenanthrenes
DBF = dibenzofuran
NDPA = n-nitrosodiphenylamine
DTP = isopimaradiene (diterpene)
unidentified diterpene (possibly kaur-16-ene)
RET = retene
4MNOL = 4-methylphenol
2MNOL = 2-methylphenol
LPAH = low molecular weight aromatic hydrocarbons
MOX = 2-methoxyphenol
BIPH = 1,1'-biphenyl
TVS = total volatile solids
TOC = total organic carbon
BZOH = benzyl alcohol
ANIL = aniline
DIB = dibenzothiophene
O&G = oil and grease
Pb = lead
As = arsenic
Zn = zinc
Ni = nickel
Hg = mercury
Cd = cadmium
Sb = antimony
Cu = copper
N = total nitrogen
S = total sulfides

[c] Chemical exceeded apparent effect threshold for toxicity only.

[d] Chemical exceeded apparent effect threshold for benthic abundance only.

[e] No benthic abundance data available for RS-24.

- The amphipod bioassay results from these stations may have reflected synergistic or additive effects of chemicals present at low concentrations relative to other Commencement Bay sites.

- The bioassay response may have resulted from the presence of some unmeasured chemical whose spatial distribution does not covary with those of the over 150 chemicals measured in this study.

Because there were no corroborative data from the oyster larvae bioassay or any benthic indicator, these alternative explanations do not appear as plausible as the grain size explanation. The only other occurrence of a significant amphipod bioassay response in the absence of other toxicity or benthic effect responses was at Station SI-15 at the mouth of Sitcum Waterway (average mortality = 25 percent). This station also had a high percentage of fine-grained material (81 percent), and retene (tentative identification) was the only chemical elevated at this station above its toxicity AET. Although chemical toxicity may be a factor at SI-15, it is possible that the single bioassay response at these five stations reflects grain size factors only. Sediment from four other biological stations in the Commencement Bay studies had a fine-grained material content ranging from 82 to 89 percent, yet did not exhibit significant amphipod mortality. Therefore, if grain size factors do influence amphipod bioassay results, a consistent pattern among all fine-grained sediments has not been demonstrated.

Significant oyster larvae abnormality was observed at two stations where no other toxic or benthic response was found. One of these stations (HY-12) had a high percentage of fine-grained material (78 percent), but the other station did not (SP-12; 49 percent). Oyster larvae abnormalities were generally higher in sediments with higher TOC levels (e.g., Figure 4.1). This correspondence was not observed between amphipod mortality and TOC. Sediments from Stations HY-12 and SP-12 were moderately enriched with organic carbon (5.7 and 4.7 percent, respectively). This organic enrichment may have been a factor in the oyster larvae results. There were no other physicochemical factors consistent between these stations. No chemical exceeded an AET (DW) at Station SP-12 (Table 4.4).

Significant benthic effects without sediment toxicity were observed at four stations (Table 4.4). No chemical exceeded an AET (DW) at Stations HY-32 or HY-37. The presence of multiple benthic depressions observed at Station HY-32 was the only such occurrence in the absence of a significant bioassay response. Stations SI-11 and RS-20 had a single significant depression of Crustacea and Mollusca, respectively. In each case, the concentration of at least one metal exceeded an AET (DW).

Toxicity and benthic AET for metals and organic compounds normalized to the sediment organic carbon content are summarized in Tables 4.5 and 4.6. A summary of chemicals with concentrations exceeding an AET normalized to TOC at each of the 29 stations exhibiting a significant toxic response or benthic effect is given in Table 4.7. Analogous results for chemicals normalized to percent fine-grained material are given in Tables 4.8, 4.9, and 4.10. The format of these tables and the approach used to determine "apparent effect thresholds" were the same as for Tables 4.1, 4.2, and 4.4.

TABLE 4.5. APPARENT EFFECT THRESHOLDS FOR POTENTIAL PROBLEM METALS NORMALIZED TO ORGANIC CARBON

METALS	APPARENT EFFECT THRESHOLD (mg/kg)	BIOLOGICAL STATIONS AND CONCENTRATIONS EXCEEDING THRESHOLD (mg/kg)		METALS	APPARENT EFFECT THRESHOLD (mg/kg)	BIOLOGICAL STATIONS AND CONCENTRATIONS EXCEEDING THRESHOLD (mg/kg)	
Antimony	1,900/200	RS-22	1,900	Lead	35,000/14,000	SI-11	31,000
		RS-24	3,000			SI-12	32,000
		RS-18	4,800			RS-22	35,000
		RS-19	6,200			RS-20	28,000
						RS-24	66,000
Arsenic	32,000/3,200	SI-11	4,400			RS-18	71,000
		RS-22	30,000			RS-19	180,000
		RS-20	32,000				
		RS-24	88,000	Mercury	210/77	RS-20	210
		RS-18	110,000			RS-19	550
		RS-19	270,000			RS-18	590
Cadmium	1,100/580	RS-22	780	Nickel	6,800[b]/6,300	RS-20	6,800
		RS-20	1,100				
		RS-24	1,200	Zinc	72,000/12,000	SI-12	22,000
		RS-18	2,100			SI-11	23,000
		RS-19	2,800			RS-18	38,000
						RS-20	50,000
Copper	49,00/9,700	SI-12	12,000			RS-22	72,000
		SI-11	14,000			RS-19	160,000
		RS-22	31,000			RS-24	200,000
		RS-24	48,000				
		RS-20	49,000				
		RS-18	130,000				
		RS-19	390,000				

[a] Where two values are shown, the one on left is the toxicity threshold and the one on right is the benthic effects threshold. The lower of these paired values is underlined. Where only one value is shown, the two apparent thresholds are identical.

[b] No apparent toxicity threshold was observed for this chemical. The value shown is the maximum concentration observed.

TABLE 4.6. APPARENT EFFECT THRESHOLDS FOR POTENTIAL PROBLEM ORGANIC COMPOUNDS NORMALIZED TO ORGANIC CARBON

ORGANIC COMPOUNDS	APPARENT EFFECT THRESHOLD (ug/kg)	BIOLOGICAL STATIONS AND CONCENTRATIONS EXCEEDING THRESHOLD (ug/kg)		ORGANIC COMPOUNDS	APPARENT EFFECT THRESHOLD (ug/kg)	BIOLOGICAL STATIONS AND CONCENTRATIONS EXCEEDING THRESHOLD (ug/kg)	
Phenol	39,000^{b,c}	NONE		Aniline	U 7,700^{d}	CI-11	16,000
2-Methylphenol	5,300/10,000^{c}	RS-13	10,000	N-Nitrosodiphenylamine	11,000^{b,c}	NONE	
4-Methylphenol	37,000/81,000	SP-16 RS-13 SP-15 SP-14	61,000 81,000 1,300,000 590,000	Tetrachloroethene	22,000^{b,c}	NONE	
LMW aromatic hydrocarbons	370,000/530,000^{c}	RS-13	530,000	Ethylbenzene	3,800^{b,c}	NONE	
HMW aromatic hydrocarbons	960,000/1,500,000^{c}	RS-13	1,500,000	Total xylenes	12,000^{b,c}	NONE	
Chlorinated benzenes	20,000/<21,000^{c}	RS-13	21,000	1-Methyl-2-(1-methylethyl)benzene^{e}	110,000^{b}/35,000	SI-11 SP-15 HY-17 SP-14	110,000 68,000 54,000 41,000
Chlorinated butadienes	1,600,000	HY-47	2,500,000	2-Methoxyphenol^{e}	23,000	SP-14 SP-15 SP-16	24,000 73,000 23,000
Hexachlorobutadiene	9,600/11,000	HY-42 HY-47 HY-22	11,000 16,000 16,000	1,1'-Biphenyl^{e}	7,000/12,000^{e}	RS-13 RS-18	12,000 12,000
Total phthalates	310,000^{b}/290,000	RS-19 RS-20	300,000 310,000	Dibenzothiophene^{e}	8,200/14,000	RS-18 RS-13 RS-19	12,000 14,000 17,000
Total PCBs	25,000/46,000^{c}	HY-23 HY-22 HY-42	40,000 45,000 46,000	Diterpenoid hydrocarbons Isopimaradiene^{e} Unidentified diterpene^{e,f}	 74,000^{b,c} 71,000/69,000	 NONE HY-47 SI-12 SI-11	 87,000 130,000 71,000
Benzyl alcohol	5,000	SP-16	8,800				
Dibenzofuran	15,000/58,000^{c}	RS-19 RS-18 RS-13	19,000 23,000 58,000	Retene^{e}	57,000/81,000	RS-13 SI-15 SP-16	65,000 81,000 120,000

[a] Where two values are shown, the one on left is the toxicity threshold and the one on right is the benthic effects threshold. The lower of these paired values is underlined. Where only one value is shown, the two apparent thresholds are identical.

[b] No apparent toxicity threshold was observed for this chemical. The value shown is the maximum concentration observed.

[c] No apparent benthic effects threshold was observed for this chemical. The value shown is the maximum concentration observed.

[d] Aniline was undetected at values ranging up to 7,700 ug/kg OC at all stations except CI-11.

[e] This compound was identified by matching the sample spectra with library reference spectra. The identification is considered tentative because standards of this compound are not routinely analyzed.

[f] Possibly kaur-16-ene.

TABLE 4.7. SUMMARY OF EFFECTS AND POTENTIAL PROBLEM CHEMICALS AT BIOLOGICAL STATIONS (NORMALIZED TO ORGANIC CARBON)

Toxicity and/or Benthic Effect[b]	Station	Chemical[b] Exceeding An Apparent Effect Threshold
O	HY-12	
M	HY-14	
O M C	HY-17	
O A M C	HY-22	HCBD, TPCB[b]
O A M P T	HY-23	TPCB
M C T	HY-32	
M	HY-37	
A	HY-42	HCBD, TPCB[c]
O M	HY-47	HCBD, CBEN
A	B-15	
A	BL-25	
C	SI-11	AS[d], Cu[d], Pb[d], Zn[d]
A C	SI-12	Cu[d], Pb[d], Zn[d]
A	SI-15	RET[c]
A	MI-11	
A	MI-15	
O	SP-12	
O A M C P T	SP-14	4MNOL, MOX
O A M C	SP-15	4MNOL, MOX
O A T	SP-16	4MNOL[c], BZOH, MOX, RET
O A M	CI-11	ANIL
O M C P T	CI-13	
O M C P T	CI-16	
O A	CI-20	
O A	RS-13	2MNOL[c], LPAH[c], HPAH[c], CBEN, DBF[c], BIPH[c], DIB[c], RET[c]
O A M C P T	RS-18	DBF[c], BIPH[c], DIB[c], Sb, As, Cd, Cu, Pb, Hg, Zn[d]
O A M	RS-19	PHTH[d], DBF[c], DIB, Sb, As, Cd, Cu, Pb, Hg, Zn
M	RS-20	PHTH[d], As[d], Cd[d], Cu[d], Pb[d], Hg[d], Ni[d], Zn[d]
A[e]	RS-24	Sb, As, Cd, Cu, Pb, Zn

NOTE: See Table 4.4 for footnotes.

TABLE 4.8. APPARENT EFFECT THRESHOLDS FOR POTENTIAL PROBLEM CHEMICALS NORMALIZED TO FINE-GRAINED MATERIAL

METALS	APPARENT EFFECT THRESHOLD (mg/kg)	BIOLOGICAL STATIONS AND CONCENTRATIONS EXCEEDING THRESHOLD (mg/kg)		METALS	APPARENT EFFECT THRESHOLD (mg/kg)	BIOLOGICAL STATIONS AND CONCENTRATIONS EXCEEDING THRESHOLD (mg/kg)	
Antimony	410/11	RS-20	31	Lead	7,700/790	SI-11	830
		RS-24	160			RS-20	1,300
		RS-22	410			RS-22	7,700
		RS-19	1100			RS-24	3,300
		RS-18	1300			RS-18	19,000
						RS-19	32,000
Arsenic	6,600/160	RS-20	1,500			CI-11	1,800
		RS-24	4,400				
		RS-22	6,600	Mercury	11/3.6	RS-20	10
		RS-18	29,000			RS-22	11
		RS-19	48,000			RS-19	100
						RS-18	160
Cadmium	170/25	RS-20	52	Nickel	780[b]/250	RS-18	280
		RS-24	60			RS-20	330
		RS-22	170			RS-19	720
		RS-19	500			RS-22	780
		RS-18	550				
				Zinc	16,000/640	CI-11	830
Copper	6,800/550	RS-24	2,400			RS-20	2,400
		RS-20	2,400			RS-18	10,000
		RS-22	6,800			RS-24	10,000
		RS-18	34,000			RS-22	16,000
		RS-19	70,000			RS-19	28,000

[a] Where two values are shown, the one on left is the toxicity threshold and the one on right is the benthic effects threshold. The lower of these paired values is underlined. Where only one value is shown, the two apparent thresholds are identical.

[b] No apparent toxicity threshold was observed for this chemical. The vlaue shown is the maximum concentration observed.

TABLE 4.9. APPARENT EFFECT THRESHOLDS FOR POTENTIAL PROBLEM ORGANIC COMPOUNDS NORMALIZED TO FINE-GRAINED MATERIAL

ORGANIC COMPOUNDS	APPARENT EFFECT THRESHOLD (ug/kg)	BIOLOGICAL STATIONS AND CONCENTRATIONS EXCEEDING THRESHOLD (ug/kg)	
Phenol	3,800[b]/1,800	SP-14	2,600
		CI-11	2,800
		RS-19	3,100
		RS-22	3,800
2-Methylphenol	780[b]/570	RS-22	780
4-Methylphenol	1,200/4,500	SP-16	1,600
		CI-16	1,600
		RS-13	4,500
		SP-15	10,000
		SP-14	140,000
LMW aromatic hydrocarbons	16,000/29,000	RS-13	29,000
		RS-19	40,000
		RS-18	61,000
HMW aromatic hydrocarbons	42,000/82,000	RS-13	82,000
		RS-18	93,000
		RS-19	98,000
Chlorinated benzenes	2,300[b]/1,200	HY-22	1,800
		RS-22	2,300
Chlorinated butadienes	82,000[b,c]	NONE	
Hexachlorobutadiene	2,000[b]/580	HY-22	970
		RS-22	2,000
Total phthalates	21,000	RS-19	54,000
Total PCBs	1,200/1,400	HY-42	1,400
		HY-23	1,700
		HY-22	2,600
Benzyl alcohol	780[b]/180	SP-14	240
		RS-19	310
		RS-22	780
Dibenzofuran	960/3,200	RS-13	3,200
		RS-19	3,400
		RS-18	6,000
Aniline	U1600[d]	CI-11	3,600
N-Nitrosodiphenylamine	500	RS-18	1,800
Tetrachloroethene (or other volatiles)	1,000[b,c]	NONE	
1-Methyl-2-(1-methylethyl)benzene[e]	2,900/2,000	SI-11	2,900
		HY-17	4,200
		SP-15	5,400
		SP-14	9,900
2-Methoxyphenol[e]	1,700	SP-15	5,800
		SP-14	5,900
1,1'-Biphenyl[e]	460/640	SP-14	470
		RS-13	640
		RS-19	720
		RS-18	3,300
2-Methylphenanthrene[e]	930/1,400	HY-22	980
		RS-13	1,400
		RS-19	3,100
		RS-18	7,200
1-Methylpyrene[e]	500/600	RS-13	800
		HY-22	1,600
		HY-17	2,200
		RS-18	2,600
		RS-19	2,800
Dibenzothiophene[e]	430/780	CI-11	480
		RS-19	3,000
		RS-18	3,300
Pentachlorocyclopentane[e]	130[b,c]	NONE	
Diterpenoid hydrocarbons			
Isopimaradiene[e]	2,700	SP-14	8,900
Unidentified diterpene[e,f]	3,500	SP-15	4,200
		SP-14	7,800
Retene[e]	2,300/3,600[c]	RS-19	3,000
		SP-16	3,100
		RS-13	3,600

[a] Where two values are shown, the one on left is the toxicity threshold and the one on right is the benthic effects threshold. The lower of these paired values is underlined. Where only one value is shown, the two apparent thresholds are identical.

[b] No apparent toxicity threshold was observed for this chemical. The value shown is the maximum concentration observed.

[c] No apparent benthic effects threshold was observed for this chemical. The value shown is the maximum concentration observed.

[d] Aniline was undetected at concentrations ranging up to 360 ug/kg fine grained material at all stations except CI-11.

[e] This compound was identified by matching the sample spectra with library reference spectra. The identification is considered tentative because standards of this compound are not routinely analyzed.

[f] Possibly kaur-16-ene.

TABLE 4.10. SUMMARY OF EFFECTS AND POTENTIAL PROBLEM CHEMICALS AT BIOLOGICAL STATIONS (NORMALIZED TO FINE-GRAINED MATERIAL)

Toxicity and/or Effect[a]	Station	Chemical[b] Exceeding An Apparent Effect Threshold
O	HY-12	
M	HY-14	
O M C	HY-17	MBEN, MPYR
O A M C	HY-22	CBEN[d], HCBD[d], TPCB, MPHEN[c], MPYR
O A M P T	HY-23	TPCB
M C T	HY-32	
M	HY-37	
A	HY-42	TPCB[c]
O M	HY-47	
A	B-15	
A	BL-25	
C	SI-11	MBEN[d], Pb[d]
A C	SI-12	
A	SI-15	
A	MI-11	
A	MI-15	
O	SP-12	
O A M C P T	SP-14	PNOL[d], 4MNOL, BZOH[d], MBEN, MOX, BIPH[c], DTP
O A M C	SP-15	4MNOL, MBEN, MOX
O A T	SP-16	4MNOL[c], RET[c]
O A M	CI-11	PNOL[d], DIB[c], Pb[d], Zn[d]
O M C P T	CI-13	
O M C P T	CI-16	4MNOL[c]
O A	CI-20	
O A	RS-13	LPAH[c], MPYR[c], HPAH[c], 4MNOL[c], DBF[c], BIPH[c], MPHEN[c], RET[c]
O A M C P T	RS-18	LPAH, HPAH, NDPA, DBF, BIPH, DIB, MPHEN, MPYR, Sb, As, Cd, Cu, Pb, Hg, Zn[d]
O A M	RS-19	LPAH, HPAH, PHTH, PNOL[d], DBF, BZOH[d], BIPH, DIB, MPHEN, RET[c], MPYR, Sb, As, Cd, Cu, Pb, Hg, Ni[d], Zn
M	RS-20	Sb[d], As[d], Cd[d], Pb[d], Hg[d], Ni[d], Zn[d]
A[e]	RS-24	SB[d], As[d], Cd[d], Cu[d], Pb[d], Zn[d]

NOTE: See Table 4.4 for footnotes.

The rationale for evaluating potential contaminant relationships with sediment toxicity and biological effects based on these normalizations was summarized in Section 3.1.2. Briefly, effects may be produced by contaminants found in low concentration when normalized to dry weight but present in high concentration when normalized to organic carbon or fine-grained sediments (two major chemical binding factors in sediments).

The purpose of Tables 4.5-4.10 is to compare the distribution of potential problem chemicals with that indicated in Table 4.4 for dry-weight normalized concentrations. Chemicals exceeding an AET at selected stations regardless of the method of normalization included:

- Chlorinated compounds, including total PCBs and hexachlorobutadiene
- Low and high molecular weight PAH
- 4-Methylphenol
- Bis-2-(ethylhexyl)phthalate and di-n-butylphthalate esters
- All metals of concern, including antimony, arsenic, cadmium, copper, lead, mercury, nickel, and zinc.

Organic carbon and percent fine-grained material normalizations did not reveal any chemicals above either their toxicity or benthic AET at the six stations (20 percent) discussed previously where AET were not exceeded on a dry-weight basis. Chemicals were below both AET at 48 percent (14/29) of the "affected" stations when normalized to total organic carbon. Chemicals were below both AET at the same percentage of stations (different distribution) when normalized to percent fine-grained material. For most sediments with multiple toxicity and benthic effects, chemicals exceeded an AET regardless of normalization. An obvious exception was City Waterway, where none of the sediments, including three samples with multiple significant bioassay and benthic responses, had chemicals exceeding the toxicity or benthic effects AET when normalized to organic carbon. These three stations had high concentrations of both chemicals (DW) and organic carbon. These data suggest either that high concentrations (DW) of chemicals were associated with effects regardless of organic carbon-normalized concentrations, or that observed effects resulted solely from organic enrichment. The relationships among these factors for City Waterway are discussed in the following section.

Some chemicals listed in Tables 4.7 and 4.10 were present at low concentration (DW), but were found at relatively high levels with respect to the organic carbon content or percent fine-grained material of the sediments. For example, at Station RS-13, 2-methylphenol was the only chemical elevated above the sediment toxicity threshold when normalized to dry-weight (Table 4.4). After normalization to organic carbon or percent fine-grained material, concentrations of eight chemicals or chemical groups exceeded an AET at Station RS-13. For the purpose of identifying potential problem chemicals, all chemicals shown in Tables 4.4, 4.7, and 4.10 were evaluated further. In the following section, a correspondence between site-specific gradients of chemical concentrations and toxicity or benthic effects is shown for several of these chemicals.

Chemicals of concern defined in Section 3.1 that never exceeded an AET (regardless of concentration normalization) are summarized in Table 4.11. These chemicals were not considered to have a high priority for further evaluation of their potential relationship to sediment toxicity or benthic effects, even when found at high elevations above Puget Sound reference conditions.

4.2.3 Correspondence Among Chemical, Toxicity and Benthic Effects Gradients

Gradients in toxicity and benthic effects were observed along four transects in Commencement Bay study areas. These included a cross-channel transect of stations in Hylebos Segment 2 (HY-22, HY-23, HY-24), a transect of stations in St. Paul Waterway (SP-14, SP-15, SP-16, SP-12, SP-11), a transect at the head of City Waterway in Segment 1 (CI-11, CI-13, CI-17), and a transect running offshore along the Ruston-Pt. Defiance Shoreline in Segment 2 (RS-18, RS-19, RS-20). Stations located on these transects included 11 of the 29 stations with significant sediment toxicity or benthic effects and all of the stations with the most extreme effects (e.g., sediment toxicity exceeding 50 percent mortality and abnormality plus multiple depressions of the five benthic indicators).

In this section, concentration gradients of chemicals exceeding an AET are correlated with toxicity and benthic effects gradients along each transect. The discussion focuses on chemicals with concentrations exceeding apparent effect thresholds regardless of the normalization used. The substantial change in DW concentrations of these chemicals along the four transects resulted in clear trends for potential problem chemicals in each area. Linear correlation analysis and factor analysis (varimax rotation) of data subsets were used to corroborate possible relationships among the chemical, toxicity, and benthic effects variables that are summarized in the summary plots within these sections.

4.2.3.1 Hylebos Waterway--

Within Hylebos Waterway, multiple significant bioassay responses and benthic effects were observed only at Stations HY-22 and HY-23 in Segment 2. Toxicity and benthic effects generally decreased cross-channel from Station HY-22 to Station HY-24 (e.g., see Figures 3.44 and 3.49 in Section 3.3). Total PCBs and hexachlorobutadiene exceeded apparent effect thresholds for either sediment toxicity or benthic effects regardless of normalization at Station HY-22 (Tables 4.4, 4.7, and 4.10). The correspondence among total PCB concentrations, amphipod mortality, and oyster larvae abnormality is shown in Figure 4.3 for these stations.

Stations HY-42, HY-43, and HY-44 constituted a second cross-channel transect in Hylebos Segment 5. Total PCBs were also elevated above the AET at Station HY-42 regardless of the means of normalization. Total PCB data for these latter three stations are also included for comparison in Figure 4.3. Amphipod mortality and oyster larvae abnormality decreased with decreasing PCB concentrations (DW) along both transects.

TABLE 4.11. CHEMICALS OF CONCERN WITH CONCENTRATIONS NEVER EXCEEDING APPARENT EFFECT THRESHOLDS

Chemical of Concern[a]	Concentration Range With No Effects Observed (ug/kg dry-weight)
Beryllium	80 - 450
Chromium	5,400 - 37,000
Silver	80 - 560
1,3-Dichlorobenzene	U[b] 1 - 170
Butylbenzyl phthalate	14 - 470
Di-n-octyl phthalate	6 - 420
Diethyl phthalate	2 - 73
Trichlorinated butadienes	U 5 - 30,000
Tetrachlorinated butadienes	U 10 - 14,000

[a] Chemicals of concern are those present in at least some Commencement Bay sediments at concentrations that exceed all Puget Sound reference conditions.

[b] U: Undetected at the detection limit indicated for the lower range of concentrations.

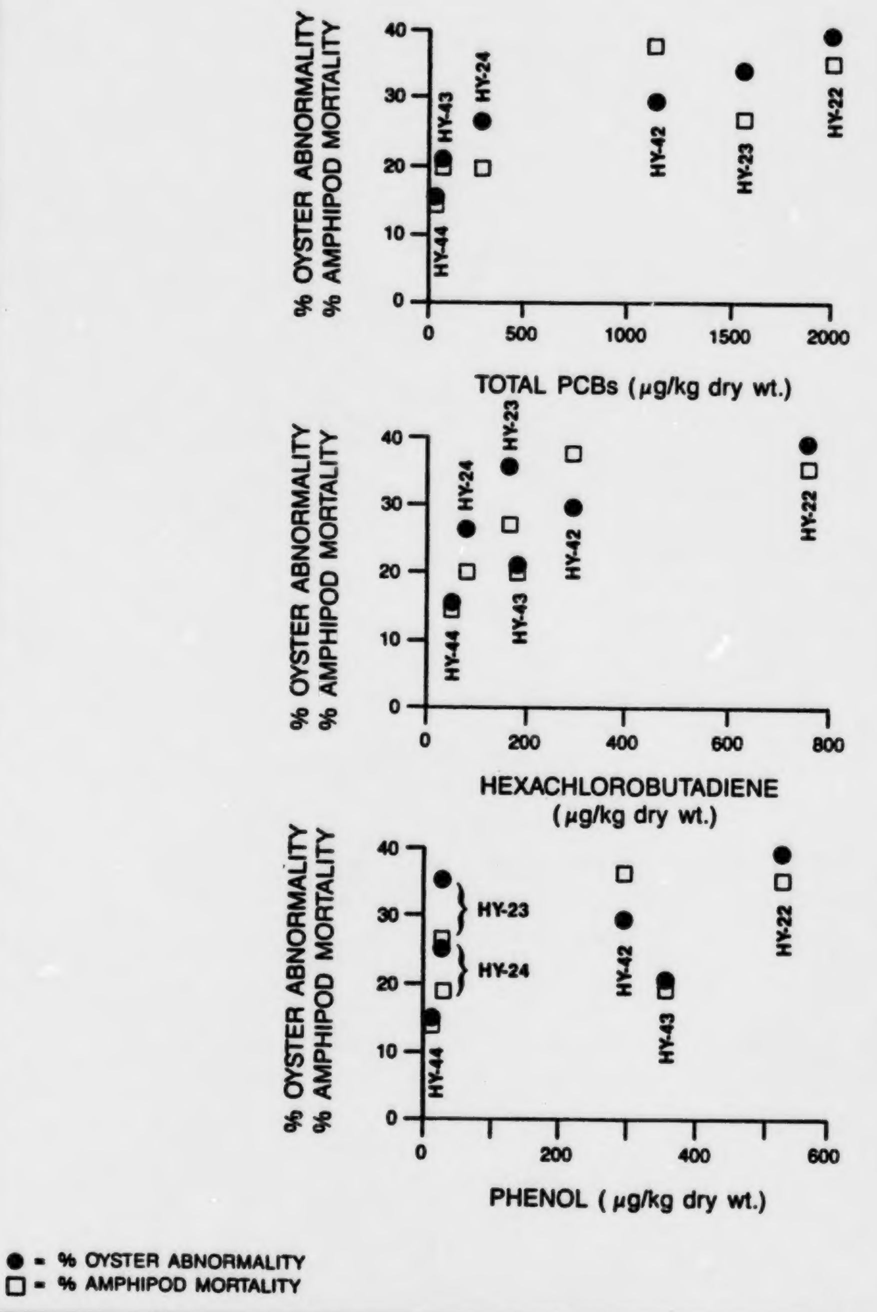


Figure 4.3. Correlation plots of sediment toxicity indicators and selected chemicals at Hylebos Waterway cross-channel biology stations (HY-22, HY-23, HY-24, and HY-42, HY-43, and HY-44).

Although concentrations of other chemicals exceeded the toxicity AET along both transects, only PCBs showed strong linear relationships along both transects. For example, although hexachlorobutadiene (HCBD) concentrations exceeded the toxicity AET at Stations HY-22 and HY-23 in Segment 2, and at Station HY-42 in Segment 5, and corresponded generally to observed toxicity, the relationships within each transect differed.

Linear trends did not emerge for several other contaminants with concentrations (DW) exceeding an AET at Station HY-22. For example, although phenol concentrations exceeded the threshold, a linear exposure-response relationship was not observed (Figure 4.3).

Mollusca was the only taxon significantly depressed at stations over the entire length of Hylebos Waterway. Total mollusc abundance consistently decreased with increasing total PCB concentrations at Stations HY-24, HY-23, and HY-22 (e.g., Figure 4.4). Total infauna and polychaete abundances were significantly depressed only at Station HY-23 along this transect, although the overall chemical contamination at Station HY-22 was higher. These latter variables showed no linear relationship with PCB concentrations. The abundances of total taxa and polychaetes decreased with increasing nickel concentrations (DW) along the transect as shown in Figure 4.4. The linear correlation of these relationships improved after normalization to organic carbon, but nickel exceeded its AET at Station HY-22 and HY-23 only when normalized to dry-weight. Changes in arsenic or other metal concentrations (DW) did not correspond with observed benthic effects gradients.

Within Hylebos Waterway, stronger relationships were found between contaminants and sediment toxicity than between contaminants and benthic effects. Organic compounds, especially PCBs, dominated the list of potential problem chemicals in the waterway. Although metals contamination in upper Hylebos Waterway was significant, toxicity or benthic effects gradients did not appear to correspond with concentration gradients of metals, with the possible exception of nickel.

4.2.3.2 St. Paul Waterway--

Within St. Paul Waterway, 100 percent mortality and abnormality and significant depressions of all major taxa groups were found at Station SP-14 off the main outfall of Champion International. Organic enrichment resulting in sediment anoxia may have contributed to the observed effects, at least at SP-14 (see Figure 3.3). Station SP-15, located on a transect away from the main outfall also had high mortality and abnormality (>50 percent) and exhibited significant depressions of Mollusca and Crustacea. Organic enrichment (only 2.1 percent TOC) did not appear to be a factor at this station. TOC, total volatile solids (4.3 percent) and sulfide content (minimum estimate of 2.6 mg/kg DW) resembled those found in sediments from nonurbanized regions of Puget Sound. Therefore, given the gross physicochemical differences observed at SP-14 and SP-15, the observed high level of toxicity and benthic effects at both these stations did not appear to be related solely to conventional factors (e.g., organic enrichment).

4-Methylphenol was found at elevated concentrations (DW) that decreased with distance from Station SP-14 off the main outfall. The linear relationship of sediment toxicity to 4-methylphenol concentration at the five stations

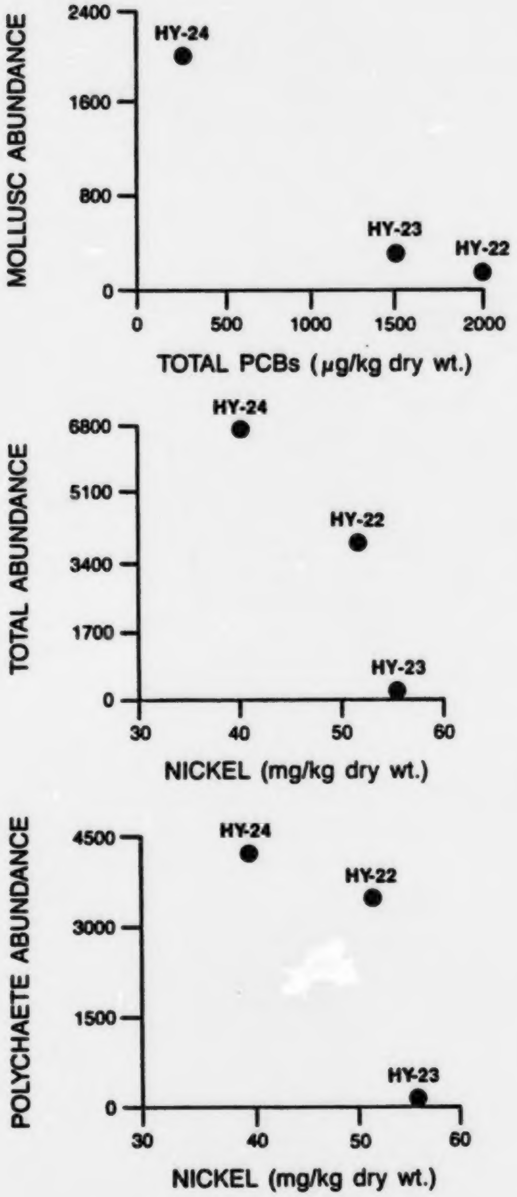


Figure 4.4. Correlation plots of benthic indicators and selected chemicals at Hylebos Waterway cross-channel stations (HY-22, HY-23, HY-24).

in St. Paul Waterway (Figure 4.5) suggested that the toxicity gradient resulted from 4-methylphenol or from a contaminant with a spatial distribution similar to that of 4-methylphenol. Extrapolation of this strong trend [excluding the high concentration (and 100 percent mortalitiy and abnormality) found at Station SP-14] suggest that 100 percent mortality and abnormality might be expected at 4-methylphenol concentrations exceeding 4,000 and 4,800 ug/kg DW, respectively.

2-Methoxyphenol and phenol were also elevated above an AET regardless of concentration normalization along this transect, but did not show the consistent gradient with sediment toxicity as found for 4-methylphenol (Figure 4.5). Retene concentrations, which peaked at Station SP-16, correlated negatively with the toxicity and benthic effects gradients.

Benthic effects in St. Paul Waterway, were not correlated as well with individual contaminant concentrations as were sediment toxicity indicators. All four major benthic taxa were significantly depressed at Station SP-14. Total crustacean abundances consistently increased with decreasing 4-methylphenol concentrations (Figure 4.6), although mollusc abundances did not. Mollusc abundances were best correlated with the distribution of the tentatively identified 1-methyl-2-(1-methylethyl)benzene (Figure 4.6). Total taxa and polychaete abundances showed no consistent trend with any contaminant concentration along the transect, although both indicators were significantly depressed at Station SP-14, where highest concentrations of several of the contaminants were found. There were no strong correlations between indicators of sediment toxicity or benthic effects and indicators of organic enrichment (i.e., TOC, TVS).

Organic compound contamination apparently was a major factor associated with significant toxicity and benthic effects in St. Paul Waterway. Except for nickel (at Station SP-14 only), no metals exceeded either AET in the waterway, and nickel did not correlate with observed effects. 4-Methylphenol was the only contaminant having a concentration trend consistent with the toxicity trend along the entire waterway. Concentrations of this alkylated phenol also showed some relationship with the observed change in crustacean abundances. Two tentatively identified organic compounds had stronger correlations with the depressions observed for molluscs. Total taxa and polychaetes also may have been affected by these contaminants, but a clear relationship was not apparent.

4.2.3.3 City Waterway--

Multiple sediment toxicity and benthic effects were observed in City Waterway. Effects decreased with distance from the head of the waterway (Stations CI-11, CI-13, and CI-17). Severe effects were also observed at the single biological station in the Wheeler-Osgood branch of the waterway, but sediments in this isolated arm of City Waterway appeared to be chemically distinct from those in the main portion of the waterway and are not included in the following discussion.

Unlike the areas already discussed, there were no chemical contaminants that exceeded either AET in City Waterway when normalized to percent TOC, even at the most severely affected stations. The decline in sediment toxicity away from the head of City Waterway was accompanied by a decline in TOC,

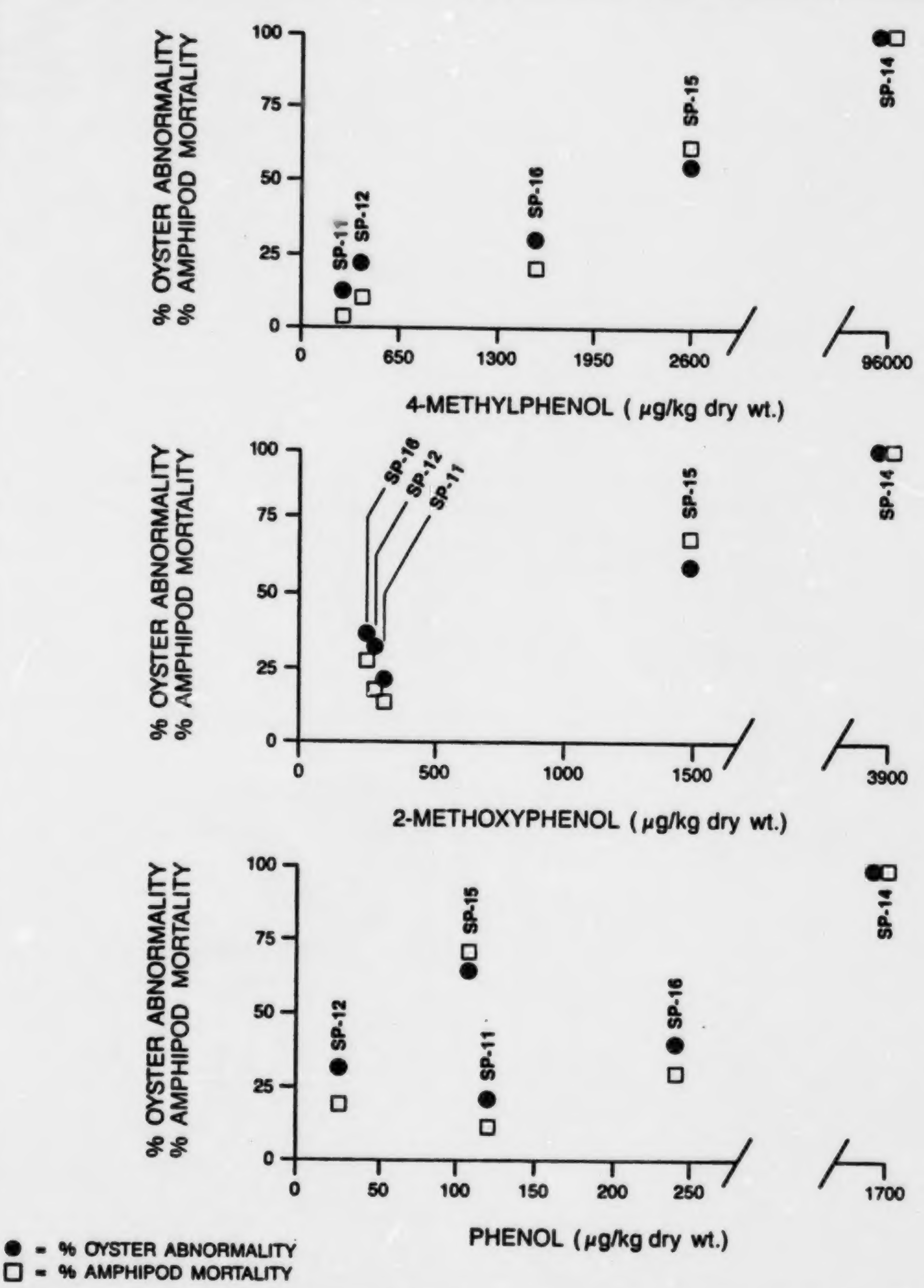


Figure 4.5. Correlation plots of sediment toxicity indicators and selected chemicals at St. Paul Waterway stations (SP-11, SP-12, SP-14, SP-15, and SP-16).

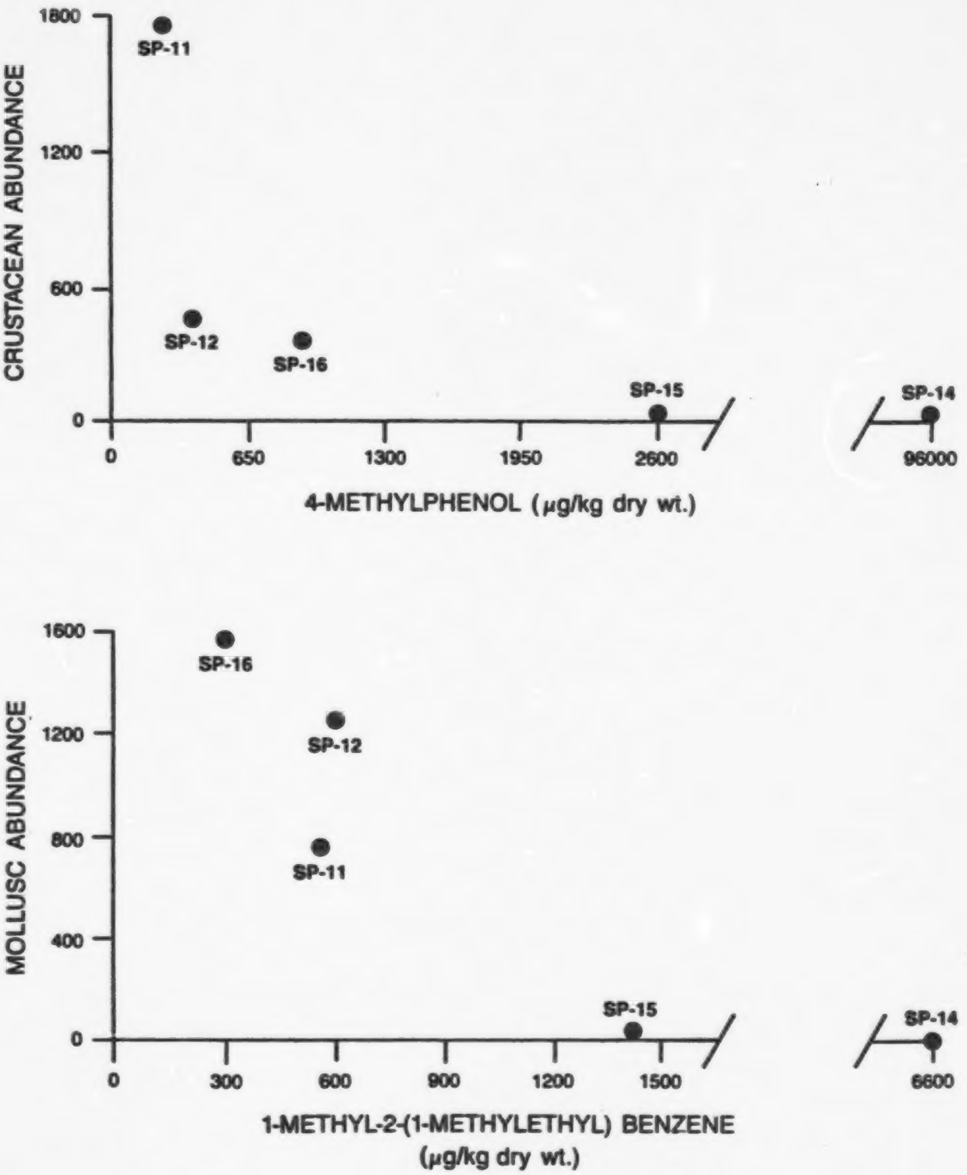


Figure 4.6. Correlation plots of benthic indicators and selected chemicals at St. Paul Waterway stations (SP-11, SP-12, SP-14, SP-15, and SP-16).

as shown in Figure 4.7. A similar decline was observed for lead and zinc concentrations (DW). The observed toxicity correlated more closely with TOC than with any other contaminant. There are insufficient data to determine whether the observed toxicity resulted from toxic contaminants or organic enrichment, although TOC levels were nearly twice as high at some stations in other waterways without significant toxicity or benthic effects. At the head of City Waterway, the source of organic enrichment appeared to be the source of toxicity, as well as the cause of depressed abundances of molluscs and crustacea (e.g., Figure 4.8). An exception to these trends was observed for polychaete abundances, which were most depressed at Station CI-13. Polychaete abundances decreased in direct proportion to increasing mercury concentrations, as shown in Figure 4.8.

4.2.3.4 Ruston-Pt. Defiance Shoreline--

High levels of all metals and several organic compounds were observed at Station RS-18, located directly off the main outfall of ASARCO along the Ruston-Pt. Defiance Shoreline. Concentrations of all of these contaminants generally decreased along an onshore-offshore transect of biological stations including RS-18, RS-19, and RS-20. This decrease in contamination corresponded to a decrease in sediment toxicity and benthic effects along the transect. The strongest linear correlations between contaminant concentrations and sediment toxicity were found for mercury and low molecular weight PAH (LPAH), which had identical distributions along this transect. Plots for concentrations of mercury normalized to DW and percent fine-grained material are shown in Figure 4.9. LPAH showed a similar trend with sediment toxicity regardless of the method of normalization. A decrease in sediment toxicity along the transect also corresponded with a general decrease of arsenic concentrations normalized to DW (Figure 4.9). However, following normalization to organic carbon or percent fine-grained material, the linear trend was disrupted. The distribution for arsenic was typical of that observed for most other contaminants (i.e., a general linear trend only when concentrations were normalized to DW).

Mollusc and polychaete abundances decreased to zero with increasing concentrations of most contaminants along the RS-20, RS-19, RS-18 transect (Figure 4.10). The major difference in the relationships was that mollusc abundances appeared to decrease exponentially while polychaete abundances decreased linearly with concentrations (DW) of various metals and organic compounds. Total crustacean and total taxa abundances were higher at RS-19 than at RS-20, which did not correspond with the concentration gradients of any contaminant normalized to dry weight.

4.2.4 Summary

A general correspondence of higher sediment contaminant concentrations, higher sediment toxicity, and lower benthic infaunal abundances was observed throughout the study area. Toxicity or benthic AET (i.e., the concentration above which all sediments had significant toxicity or benthic effects, respectively) were exceeded by a number of chemicals at most, but not all, of the 29 biological stations exhibiting significant effects. The six stations that did not have any chemicals above their toxicity or benthic AET (DW) were unusual in that the effects recorded by one biological indicator were not reflected by significant responses by the other biological indicators.

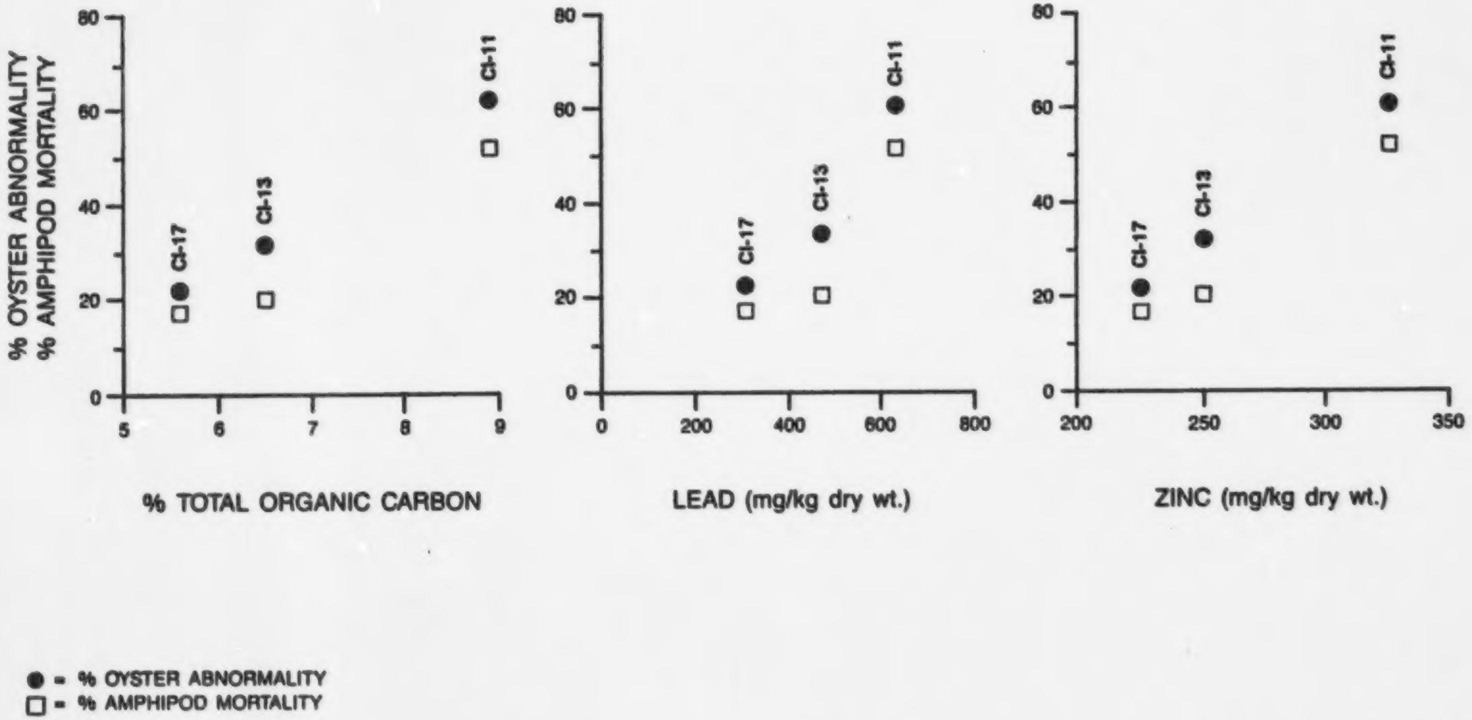


Figure 4.7. Correlation plots of sediment toxicity indicators and selected chemicals at the head of City Waterway (Stations CI-11, CI-13, and CI-17).

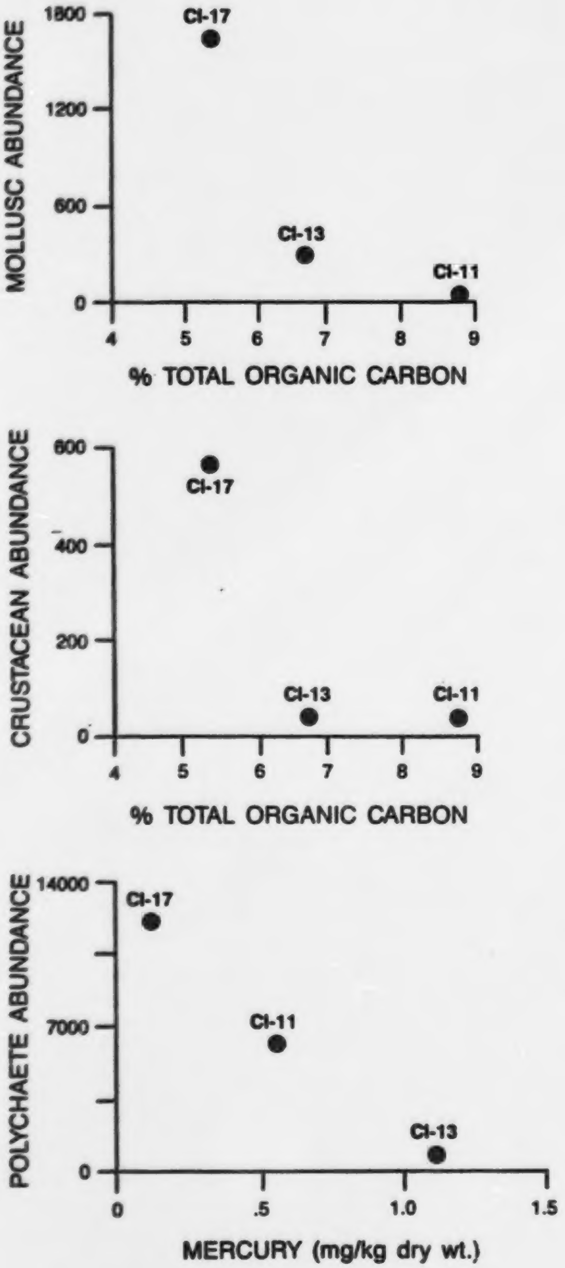


Figure 4.8. Correlation plots of benthic indicators and selected chemicals at the head of City Waterway (Stations CI-11, CI-13, and CI-17).

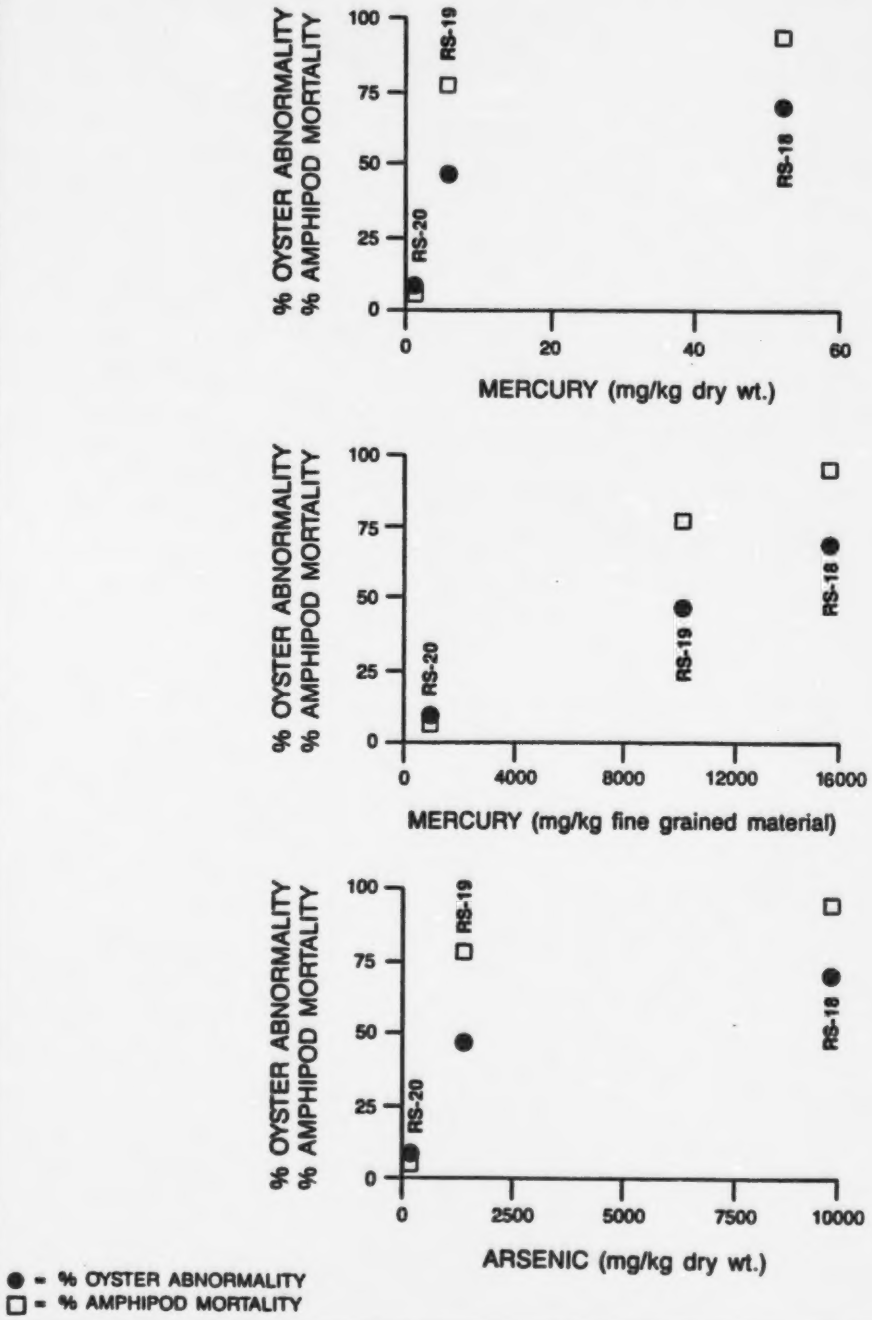


Figure 4.9. Correlation plots of sediment toxicity indicators and selected chemicals along a Ruston-Pt. Defiance offshore transect of stations (RS-18, RS-19, and RS-20).

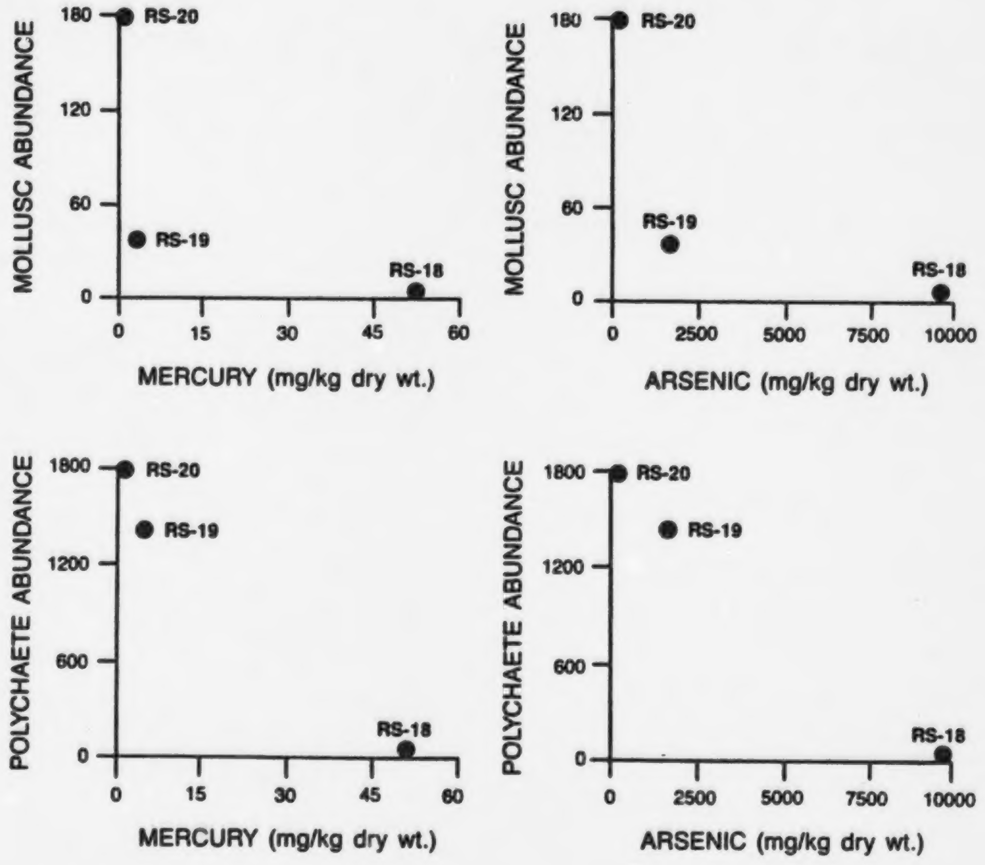


Figure 4.10. Correlation plots of benthic indicators and selected chemicals along a Ruston-Pt. Defiance offshore transect of stations (RS-18, RS-19, and RS-20).

Most of these stations exhibited toxicity by the amphipod bioassay only, and the toxicity may have been related to the high percentage of fine-grained material (>80 percent) at each station. A difference in the toxicity and benthic effects threshold for several chemicals suggests that the bioassays were more sensitive to organic compound contamination and benthic depressions were more sensitive to metals contamination.

An analysis of effects gradients was possible along four transects of biological stations in Commencement Bay. Strong relationships were observed for a limited number of the chemicals that exceeded an AET in each of these areas. Patterns consistent with exposure-response relationships included:

- PCB concentrations, sediment toxicity, and mollusc abundance along a Hylebos Waterway transect
- 4-Methylphenol concentrations, sediment toxicity, and crustacean abundance along a St. Paul Waterway transect
- Organic enrichment, lead, zinc, sediment toxicity, mollusc abundance, and crustacean abundance along a City Waterway transect
- Mercury concentrations and polychaete abundance along the same City Waterway transect
- Mercury and LPAH concentrations, and sediment toxicity along a Ruston-Pt. Defiance transect leading offshore
- Most metal and organic compound concentrations with mollusc and polychaete abundances along the same Ruston-Pt. Defiance Shoreline transect.

The stations along these four transects included those stations with the most extensive toxicity and benthic effects observed in Commencement Bay. Sediment toxicity tended to correlate better with contaminant concentrations than did benthic effects. Because bioassays were conducted on an aliquot of the same homogenized sediment sample used for chemical analyses, whereas benthic samples were collected synoptically with the bioassay-chemistry samples, but were not the identical sediments, some of the variability associated with contaminant-benthic infauna relationships may reflect random variability at the site.

4.3 COMPARISON OF BIOASSAY RESPONSES WITH BENTHIC INVERTEBRATE ASSEMBLAGES

This section examines the degree of consistency between bioassays and benthic infauna as indicators of environmental contamination. In the present study, each indicator was used to determine a different type of response. Bioassays represented the acute (i.e., hours to days) responses of individual species (i.e., *Rhepoxinius abronius*, *Crassostrea gigas*) to sediment removed from its natural setting, whereas benthic infauna represented the in situ chronic (i.e., weeks to months) responses of groups of organisms (i.e., major taxa). The primary objective of the following comparisons is to determine whether the two indicators gave similar patterns with respect to identifying contaminated areas. If the patterns are similar, future studies may be able to rely on only one of these indicators. Comparisons were based on the 48 stations at which both indicators were evaluated in March, 1984.

4.3.1 Correlation of Indicators

Amphipod mortality and oyster abnormality were correlated with the abundances of five major benthic invertebrate taxa (total taxa, Polychaeta, Mollusca, Crustacea, and Echinodermata) using the product-moment correlation coefficient (Table 4.12). All but one of the correlation coefficients (total taxa-oyster abnormality) was negative. However, none of the coefficients was significant ($P>0.05$). These results indicate that simple linear relationships did not exist between bioassay responses and the abundances of major benthic invertebrate taxa.

4.3.2 Comparison of Bioassays with Benthic Groupings

Values of amphipod mortality and oyster abnormality were compared with the groupings of stations determined by classification analysis of benthic invertebrate assemblages (Section 3.2). This comparison was made to determine whether stations with different benthic assemblages (based on species composition and abundance) exhibited different (or characteristic) bioassay responses.

Results were similar for both the amphipod and oyster bioassays (Figure 4.11). Bioassay values for Groups I-VII overlapped considerably, indicating that characteristic bioassay responses did not correspond to these different benthic assemblages. All bioassay values for Groups I-VII were less than 50 percent.

Bioassay values for Group VIII and the three ungrouped (i.e., unique) stations (RS-18, RS-19, and SP-14) did not overlap with values from Groups I-VII and, except for oyster abnormality at RS-19 (47 percent), exceeded 50 percent. Benthic assemblages at all of these stations were considerably different from those found at the remaining stations sampled in this study. Group VIII consisted of Stations CI-11 and SP-15, where nematodes and Capitella capitata dominated benthic assemblages. Also, abundances of molluscs at CI-11 and SP-15 (4 and 50 individuals/m^2, respectively) were third and fifth lowest in the study. Stations RS-18 and SP-14 had the lowest abundances of total benthic invertebrates (29 and 133 individuals/m^2, respectively) in the study. In addition, polychaetes and molluscs were absent from Station RS-18 and molluscs were absent from Station SP-14. These were the only stations at which these major taxa were absent. Finally, Station RS-19 had the fourth lowest abundance of molluscs (33 individuals/m^2) in the study. Thus, bioassay values greater than 50 percent identified the most unique (and presumably most severely impacted) benthic assemblages in the study.

4.3.3 Comparison of Significant Responses

The relationship of significant and nonsignificant amphipod and oyster larvae bioassay results (Section 3.3) to presence or absence of one or more significantly depressed benthic invertebrate taxa (Section 3.2) at

TABLE 4.12. CORRELATIONS[a] OF ABUNDANCES OF MAJOR BENTHIC INVERTEBRATE TAXA WITH AMPHIPOD MORTALITY AND OYSTER LARVAE ABNORMALITY

Taxon	Amphipod Mortality	Oyster Abnormality
Total taxa	-0.04 ns[b]	0.00 ns
Polychaeta	-0.23 ns	-0.22 ns
Mollusca	-0.24 ns	-0.33 ns
Crustacea	-0.10 ns	-0.22 ns
Echinodermata	-0.21 ns	-0.22 ns

[a] The product-moment correlation coefficient was calculated for the 48 stations at which benthic infauna and bioassays were both evaluated in March, 1984.

[b] ns = not significant at an experimentwise error rate of 0.05. Critical correlation coefficient = 0.37.

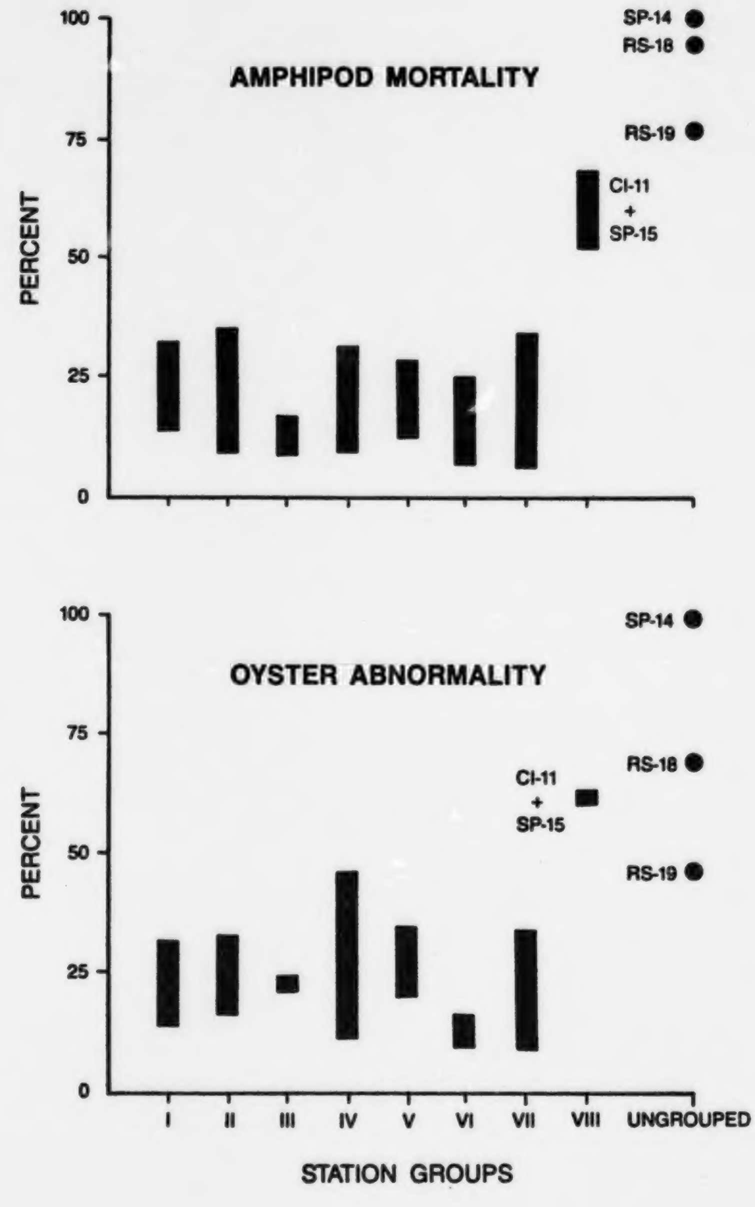


Figure 4.11. Ranges of bioassay responses for the station groupings based on classification analysis of benthic assemblages.

the 48 study sites sampled in March is presented in Figure 4.12. The distributions of responses for both bioassays were very similar. Amphipod mortality was consistent with benthic depressions at 66.6 percent (32/48) of the stations, whereas oyster abnormality was consistent at 79.2 percent (38/44) of the stations. Amphipod mortality and oyster abnormality did not confirm the presence of one or more benthic depressions at 18.8 percent (9/48) and 12.5 percent (6/48) of the stations, respectively. Conversely, amphipod mortality and oyster abnormality did not confirm the absence of benthic depressions at 14.6 percent (7/48) and 8.3 percent (4/48) of the stations, respectively.

Results of these comparisons suggest that the amphipod and oyster bioassays are similarly accurate in confirming impacts on benthic invertebrates. However, this accuracy is less than 70 percent for the amphipod bioassay and less than 80 percent for the oyster bioassay.

4.3.4 Summary

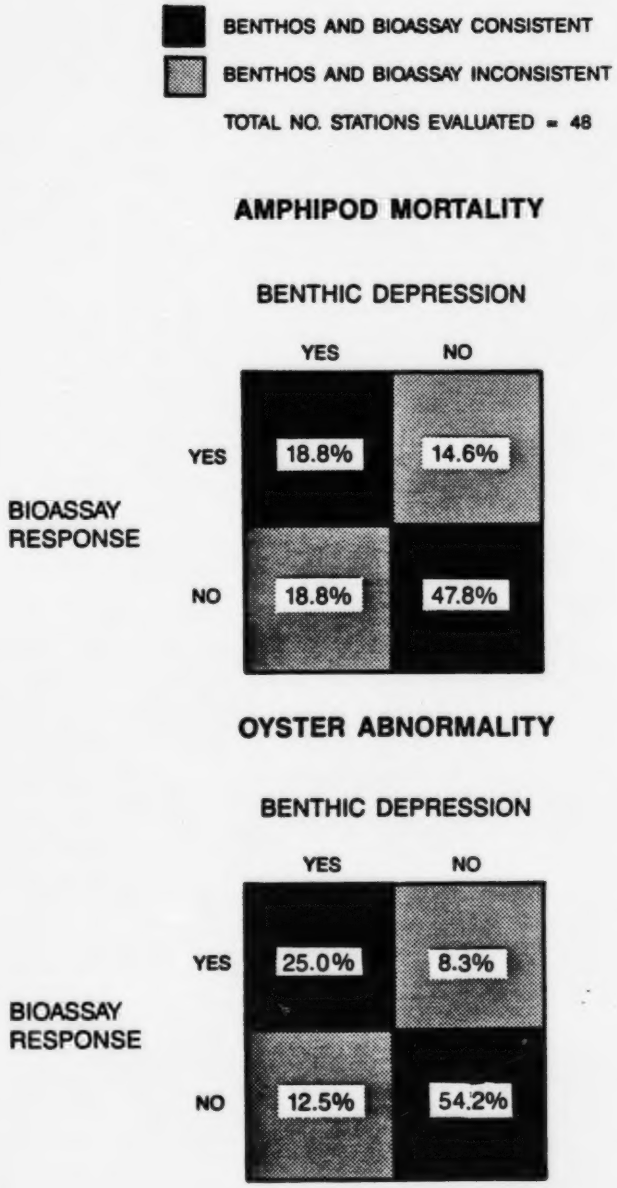
Simple linear relationships were not found between abundances of major benthic invertebrate taxa and either amphipod mortality or oyster larvae abnormality. Bioassay values less than 50 percent were not able to distinguish or characterize different benthic assemblages. Bioassay values greater than 50 percent accurately identified the most unique (and probably most severely impacted) benthic assemblages in the study. Significant amphipod mortalities and oyster abnormalities corresponded with the presence of one or more significant depressions of major benthic invertebrate taxa at 66.6 and 79.2 percent (respectively) of the stations sampled.

4.4 COMPARISONS OF LESION PREVALENCES IN ENGLISH SOLE WITH CHEMICAL CONTAMINANTS IN SEDIMENTS

Malins et al. (1984) found that prevalences of total hepatic lesions in English sole from 32 stations in Puget Sound were positively correlated ($P<0.05$, Spearman r_s) with sediment concentrations of PAH and metals. To test whether similar relationships existed in the present study, prevalences of English sole with one or more of the four hepatic lesions (Section 3.5) were compared with sediment concentrations of major classes of chemical contaminants at stations near the trawl transects. Chemical groups included PAH, metals (except iron and manganese), PCBs, chlorinated benzenes, and phthalates. Comparisons were based on 16 stations (Carr Inlet plus the 15 trawl transects in Commencement Bay) and were made using the Spearman rank correlation coefficient. Each correlation was tested at a comparisonwise error rate of 0.01 so that the experimentwise rate was 0.05. The critical r_s value for each comparison was 0.62.

Although all five correlations were positive (Figures 4.13 and 4.14), none was significant ($P>0.05$). The highest correlations were found between lesion prevalence and PAH ($r_s=0.55$) and lesion prevalence and PCBs ($r_s=0.50$).

Several factors limit comparisons between results of the present study and those of Malins et al. (1984). Although lesion classifications were standardized between studies, prevalences were based on different age distributions of English sole. Because prevalences of at least two kinds of lesions are functions of age (Section 3.5), between-study differences



■ BENTHOS AND BIOASSAY CONSISTENT

▨ BENTHOS AND BIOASSAY INCONSISTENT

TOTAL NO. STATIONS EVALUATED = 48

AMPHIPOD MORTALITY

		BENTHIC DEPRESSION	
		YES	NO
BIOASSAY RESPONSE	YES	18.8%	14.6%
	NO	18.8%	47.8%

OYSTER ABNORMALITY

		BENTHIC DEPRESSION	
		YES	NO
BIOASSAY RESPONSE	YES	25.0%	8.3%
	NO	12.5%	54.2%

Figure 4.12. Correspondence between stations having significant ($P<0.05$) bioassay responses and stations having significant ($P<0.05$) benthic depressions.

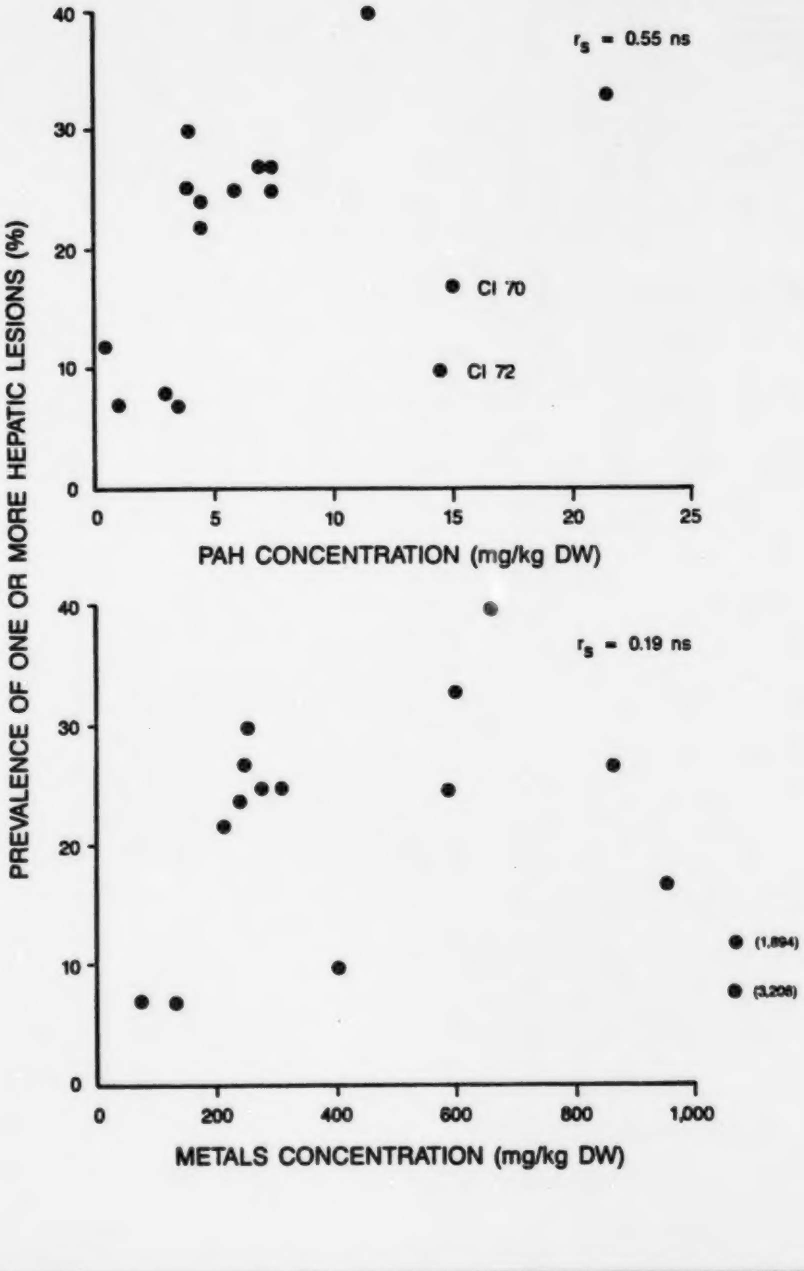


Figure 4.13. Correlations of lesion prevalence in English sole with sediment concentrations of PAH and metals. ns = P>0.05, experimentwise.

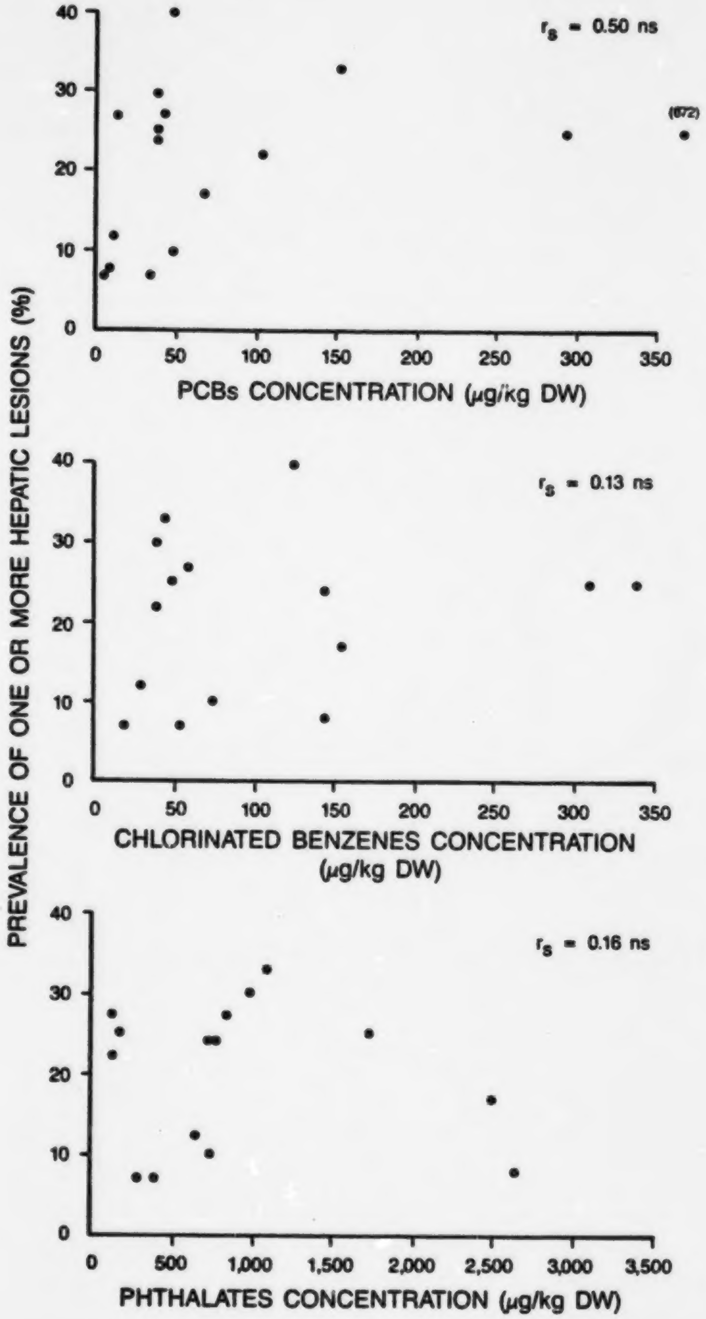


Figure 4.14. Correlations of lesion prevalences in English sole with sediment concentrations of PCBs, chlorinated benzenes, and phthalates. ns = P>0.05, experimentwise.

in age distributions may have influenced correlation results. Also, the suite of compounds used in the correlation analyses were not identical between studies. Thus, between-study differences in correlation results may have been due partly to differences in the chemical groups with which lesion prevalences were compared.

Correlations between lesion prevalence and PAH and metals in the present study were evaluated qualitatively to determine whether they showed any similarities to the patterns found by Malins et al. (1984). As noted previously, Malins et al. (1984) found significant correlations ($P<0.05$) for these chemical groups, whereas the present study did not find significant correlations ($P>0.05$).

The observed correlation with metals showed no similarities with the results of Malins et al. (1984). The correlation coefficient in the present study was 0.19, compared with the value of 0.54 found by Malins et al. (1984). Furthermore, lesion prevalence at the two stations with the highest metals concentrations (11.7 and 8.3 percent) were similar to the prevalence found at the reference site (6.6 percent).

By contrast with metals concentrations, the observed correlation with PAH concentration showed several similarities with the results of Malins et al. (1984). The correlation coefficient in the present study (0.55) was similar to the value found by Malins et al. (1984) (0.58). The reason the former coefficient was not significant whereas the latter coefficient was significant is due largely to differences in sample size between the present study ($n=17$) and Malins et al. (1984) ($n=32$). As it stands, the correlation coefficient in the present study (0.55) is very close to the critical coefficient for significance (0.62). Furthermore, if the only two apparent outliers to a monotonically increasing trend of lesion prevalence with increasing PAH concentration (Stations CI-70 and CI-72) are removed from the analysis, the correlation coefficient increases to 0.82, and becomes highly significant ($P<0.001$, experimentwise). It is interesting that the only two apparent outliers are both from City Waterway. This suggests that patterns in this waterway are unique compared to those of the other study areas. That is, although PAH concentrations at both trawl transects in City Waterway were ranked second and third in magnitude in the entire study, lesion prevalence was not exceptionally high (10.0 and 16.7 percent). Although Malins et al. (1984) also found that PAH concentrations in City Waterway (i.e., Station 23) ranked second in magnitude in their study, they did not present the lesion prevalence specific to that station.

In summary, lesion prevalence in the present study did not correlate significantly ($P>0.05$) with sediment concentrations of PAH, metals, PCBs, chlorinated benzenes, and phthalates. If the pattern found for City Waterway is considered unique and is removed from consideration, the correlation between lesion prevalence and PAH concentration becomes highly significant.

4.5 RELATIONSHIP BETWEEN BIOACCUMULATION AND SEDIMENT CONTAMINATION

This section examines the relationships between sediment contamination and bioaccumulation in English sole and crabs. The objectives are to identify the sediment contaminants that are available for bioaccumulation in indigenous organisms and to determine sediment contaminant levels above which significant bioaccumulation occurs.

4.5.1 Inorganic Substances

Sediments throughout the Commencement Bay waterways had varying elevations of inorganic substances, with concentrations generally less than 25 times reference values. Highest sediment concentrations of inorganic substances occurred along the Ruston-Pt. Defiance Shoreline, where concentrations of arsenic, copper, and lead were two to three orders of magnitude higher than reference values. Despite these levels of sediment contamination, fishes and crabs from Commencement Bay showed little evidence of tissue accumulation of inorganic substances.

The only cases in which muscle tissue concentrations of inorganic substances were not homogeneous among study areas were for copper in English sole muscle tissue, and lead and mercury in crab tissue. Areas of elevated copper concentrations in English sole muscle (Ruston-Pt. Defiance Shoreline, Sitcum and St. Paul Waterways) also displayed elevated copper levels in sediments (>10 times the reference level). English sole from other areas with high sediment copper levels (e.g., Middle Waterway) showed no evidence of muscle tissue bioaccumulation. Fish from Middle Waterway had highly elevated concentrations of copper in liver tissue, however. Therefore, there is a good relationship between elevated tissue levels of copper and corresponding sediment contamination.

The higher lead concentrations in crabs from Sitcum and City Waterways are consistent with the relatively high sediment lead concentrations in these areas. City and Sitcum Waterways both had average lead sediment concentrations about 40 times that of the reference area and were considerably higher than those of any other waterway.

Mercury tissue concentrations were highest in crabs from Hylebos Waterway. Although sediment mercury levels were elevated in this area (approximately 3.5 times reference concentrations), the highest overall sediment mercury concentrations were measured in Middle Waterway. Crabs from Middle Waterway showed no evidence of excess mercury levels. Therefore, there is no apparent overall relationship between mercury bioaccumulation by crabs and sediment contamination.

The overall pattern apparent from the metals data is that organisms with elevated tissue concentrations were generally collected in areas of measured sediment contamination. Similarly, organisms with low tissue metal levels were collected from areas of low sediment contamination. However, a lack of correspondence is indicated by the occurrence of fish and crabs with little or no tissue contamination from areas with contaminated sediments. This relationship is shown in Figure 4.15 for Hylebos Waterway English sole. In this waterway, lead, mercury, and arsenic were measured at about 10 times reference levels in the sediments. However, there was no corresponding evidence of elevated fish muscle tissue levels (i.e., <1.5 times reference). Of the metals, copper was the most elevated in Hylebos Waterway sediments (approximately 19 times reference) and also displayed a moderate increase in fish muscle tissue (approximately 5.5 times reference).

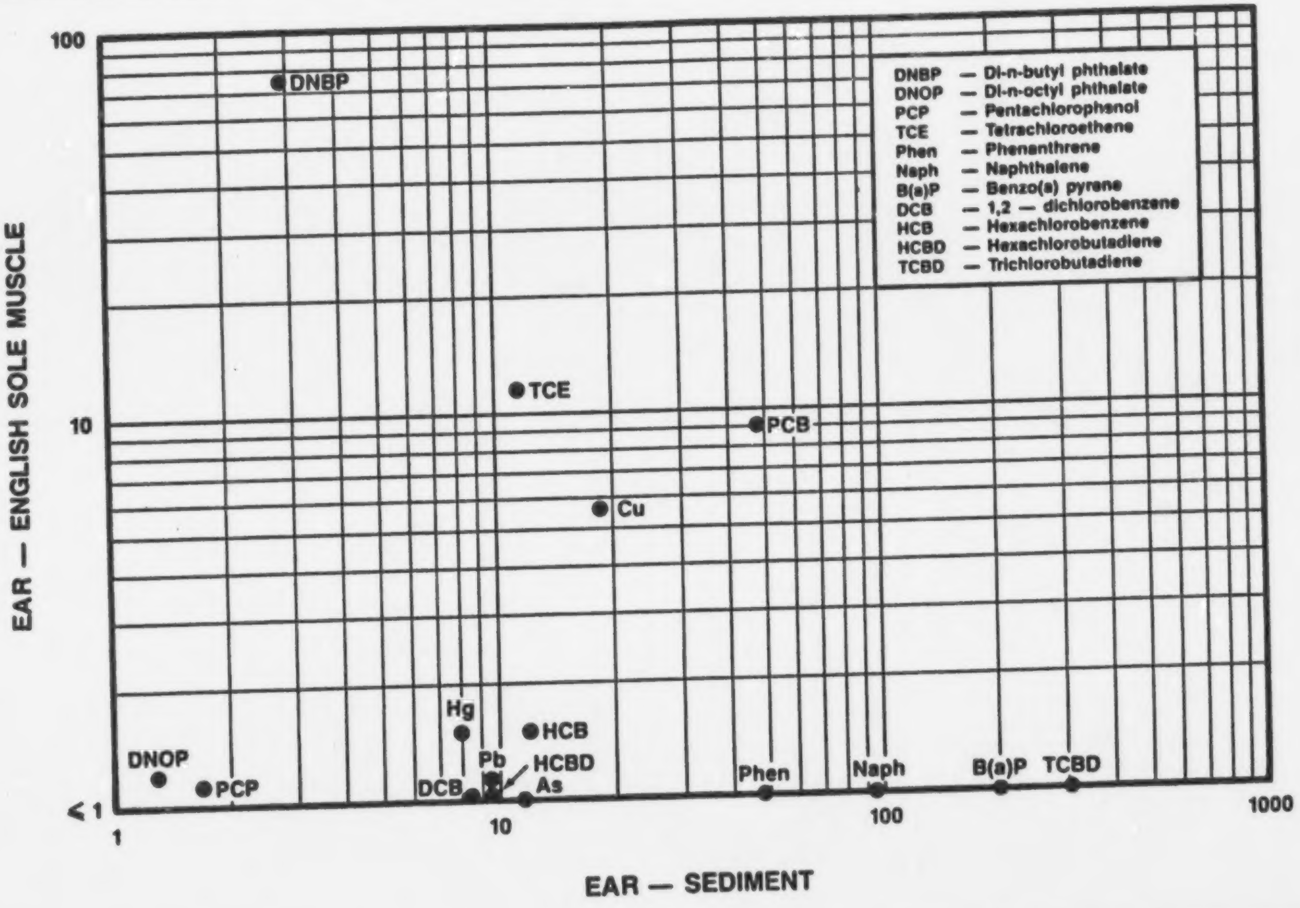


Figure 4.15. Relationship of sediment contamination to bioaccumulation in English sole in Hylebos Waterway. EAR is the ratio of contaminant concentrations in Hylebos Waterway to those in Carr Inlet.

4.5.2 Organic Substances

As was discussed in Sections 3.2 and 3.6, numerous organic substances have been detected at elevated concentrations in waterway sediments. Few organic compounds, however, are bioaccumulated in the muscle tissue of indigenous fish and crabs. Examples of organic compounds that occur in some waterway areas at average sediment concentrations greater than 100 times reference values, yet are not detected in fish or crab muscle tissue include: high molecular weight PAH, tri- and tetrachlorobutadienes, dibenzofuran, 4-methylphenol, and 2-methylnaphthalene.

The chlorinated compounds hexachlorobenzene and hexachlorobutadiene were detected at low levels only in English sole from Hylebos Waterway. Contamination of sediments by these compounds was restricted to Hylebos Waterway. Therefore, the observed bioaccumulation of hexachlorobenzene and hexachlorobutadiene corresponded directly to the measured sediment contamination.

The bioaccumulation of other organic compounds did not display such clear relationships with levels of sediment contamination. Naphthalene was significantly elevated in English sole from Milwaukee Waterway and also occurred at apparently elevated concentrations in fish from City Waterway. Although these two areas had substantial sediment contamination by naphthalene (140 and 288 times the reference levels, respectively), fish from other waterways with high sediment naphthalene levels did not display comparable tissue accumulation. Naphthalene has a relatively low bioaccumulation potential and should also be readily metabolized by fishes. The high muscle tissue levels in English sole from Milwaukee and City Waterways may have resulted from very recent exposure of the fish to water or sediment-associated naphthalene.

Phthalates were also significantly elevated in English sole from several waterway areas. Di-n-butyl phthalate was measured at a relatively high concentration in Hylebos Waterway fish. However, this compound was not substantially elevated (i.e., <3 times reference) in the sediments of any waterway. Bis-2(ethylhexyl) phthalate showed some correspondence between sediment contamination and bioaccumulation, but an overall pattern was not clear. For the phthalates in general, high sediment levels did not reliably predict potential bioaccumulation in fishes. Factors that could account for the absence of a quantitative relationship include:

- Occurrence of substantial water-mediated uptake
- Failure to identify "hot spots" of sediment contamination
- Documented occurrence of high phthalate levels in Commencement Bay sediments outside of the waterways.

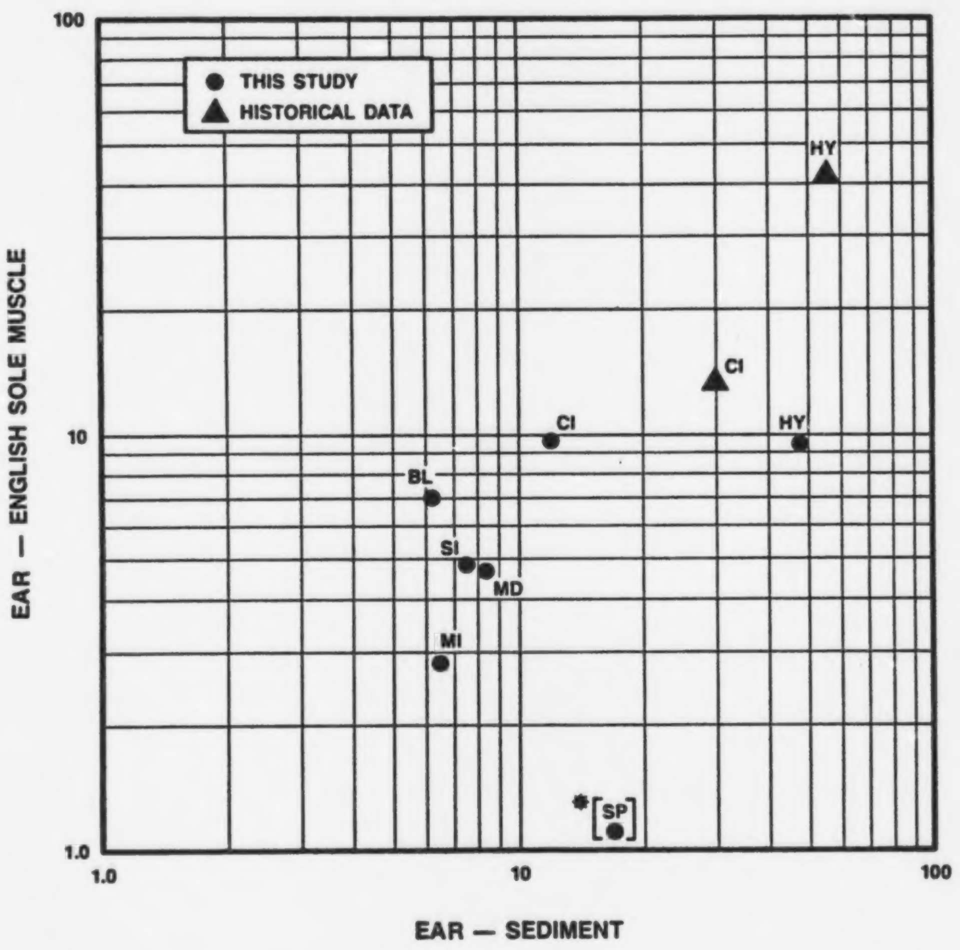
For the organic compounds, Hylebos Waterway English sole had the most detected compounds in muscle tissue. Many of the organic compounds also occurred at or near maximum levels in Hylebos fish. As is indicated in Figure 4.15, sediment elevations of organic compounds in Hylebos Waterway ranged from 1 or 2 times reference levels (e.g., pentachlorophenol) to >300 times reference levels (trichlorobutadienes). Most of the compounds detected in sediments displayed no elevations in fish muscle tissue, however.

The absence of bioaccumulation of many organic compounds results from two factors: low bioaccumulation potential and metabolism. Many of the lower molecular weight compounds detected in the sediments have low empirically determined bioconcentration factors, and therefore would not be expected to accumulate to high levels in organism tissues. Examples of this group of compounds includes pentachlorophenol, dichlorobenzenes, and trichlorobutadienes. Alternatively, PAH have a high potential for uptake that is offset by the ability of fishes and crustacea to rapidly metabolize these compounds. Experimental evidence indicates that rapid uptake of PAH by fishes is balanced by a rapid metabolism and excretion of metabolites in the bile (e.g., Stein et al. 1984; Varanasi and Malins 1977).

PCBs displayed substantial accumulations in both sediments and organism tissues from the study area. Unlike PAH, PCBs are not rapidly metabolized by organisms and tend to accumulate in tissues. In Commencement Bay waterways, PCBs occurred in muscle tissue of fishes and crabs at concentrations up to 10 times reference levels. Similar results have been observed in studies of Los Angeles harbor where, although sediments are contaminated by both PCBs and PAH, resident fishes only show evidence of PCB bioaccumulation (Gossett et al. 1983).

PCBs were subjected to more detailed evaluations of sediment-tissue relationships because of their occurrence throughout the study area and their relative health hazard. A comparison of elevations above reference for PCBs in sediments and English sole muscle tissue is presented in Figure 4.16. For Commencement Bay waterways, increasing tissue PCB levels generally corresponded with increasing sediment contamination. St. Paul Waterway did not fit this trend (i.e., there was no evidence of elevated bioaccumulation although sediments appeared to be contaminated). Examination of the sediment data for St. Paul Waterway indicated that, due to laboratory problems, PCBs were undetected at five of the six stations. For these cases, the analytical detection limits for PCBs were exceptionally high (90-180 ug/kg). Thus, the apparently high sediment PCB concentrations resulted from an average of several high detection limit values that were used as a conservative estimate of the maximum potential concentration of PCBs. This data problem was limited to the five stations in St. Paul Waterway. Because of the uncertainty in the levels of sediment PCBs in that area, the St. Paul Waterway data were excluded from statistical analyses of the sediment-tissue relationships.

Statistical analyses (Pearson correlation) of the data presented in Figure 4.16 indicated that PCB elevations in muscle tissue were significantly correlated ($r=0.82$, $P<0.05$) with sediment elevations. This relationship showed that as sediment PCB levels exceeded 10 times reference (>60 ug/kg), the sole muscle tissue concentrations were approximately 10 times reference or greater (>360 ug/kg wet weight). Bioaccumulation of PCBs to such levels in seafood organisms would result in a substantial risk to individuals eating relatively large amounts of locally caught seafood (see Section 5).



* SEE DETECTION LIMIT DISCUSSION IN TEXT

Figure 4.16. Relationship of PCB contamination of sediments and fish muscle tissue for Commencement Bay waterways.

4.5.3 Summary

There were no generalized quantitative relationships between metals concentrations in sediments and in fish tissues. These results are consistent with the ability of fishes to regulate metals, especially in muscle tissue. For organic substances, there were apparent relationships between sediment and tissue levels of chlorinated compounds. For PCBs, substantial bioaccumulation to concentrations about 10 times reference levels occurred at average sediment concentrations exceeding 60 ug/kg.

4.6 RELATIONSHIP BETWEEN BIOACCUMULATION AND FISH HISTOPATHOLOGY

This section examines the relationship between tissue contamination in English sole and the occurrence of hepatic lesions. The primary objective is to determine whether there are relationships between the accumulation of contaminants in liver tissue and the presence of liver abnormalities such as neoplasms or megalocytic hepatosis. The occurrence of such relationships could then be used to identify possible causative agents in hepatic diseases of fishes and to identify problem contaminants in the study area.

4.6.1 Inorganic Substances

Data for several inorganic constituents in fish liver samples did not pass the project quality control checks and were therefore considered to be of questionable quality. Data quality problems were associated with high variability of replicate samples and lack of accuracy for a bovine liver standard. Questionable data existed for arsenic, chromium, lead, and selenium.

Liver composite concentrations for metals with acceptable data are presented in Table 4.13. Data are presented for normal and abnormal liver composites to enable comparisons of inorganic contaminant concentrations among study areas and to evaluate whether increased contaminant levels are associated with hepatic lesions. Concentrations of the five metals (cadmium, copper, nickel, zinc, and mercury) were very similar among normal English sole liver samples from Carr Inlet, the Ruston-Pt. Defiance Shoreline, and the waterways. Although not presented in Table 4.13, liver concentrations of these metals were similarly consistent among normal English sole from individual waterways.

Concentrations of cadmium, nickel, mercury, and zinc in abnormal liver composites were also similar among lesion categories and were similar to concentrations in normal livers. Therefore, for these metals there is no evidence of differential bioaccumulation relative to study area or to health of the fish.

Copper concentrations were similar among sample groups except for a considerably elevated average concentration in the fish with various hepatic abnormalities from the Commencement Bay waterways (Table 4.13). Examination of the data indicated that this elevation was entirely the result of a very high copper concentration (189 mg/kg wet weight) in the abnormal liver sample from Middle Waterway. Normal English sole livers from Middle Waterway had a copper concentration of 4.4 mg/kg wet weight,

TABLE 4.13. AVERAGE METAL CONCENTRATIONS (mg/kg wet weight) IN ENGLISH SOLE COMPOSITE LIVER SAMPLES

Liver Condition	Location	n	Cadmium	Copper	Nickel	Zinc	Mercury
Normal	Waterways	12	0.42	5.1	0.40	19.9	0.075
Normal	Carr Inlet	2	0.41	7.2	0.39	24.6	0.060
Normal	Ruston-Pt. Defiance	3	0.56	10.1	0.46	25.3	0.097
Neoplasms	Waterways	1	0.21	3.4	0.23	21.0	0.088
Megalocytic hepatosis	Waterways	3	0.37	5.5	0.60	15.0	0.086
Multiple lesions	Waterways	4	0.46	5.9	0.69	19.0	0.098
Various abnormalities	Waterways	4	0.48	51	0.72	22.2	0.106

which was similar to those from Carr Inlet (7.2 mg/kg wet weight). Middle Waterway sediments had the highest copper concentrations among the waterways. These data suggest that fish with hepatic lesions in Middle Waterway are accumulating excess levels of copper in their livers.

4.6.2 Organic Substances

Analyses of nonvolatile organic compounds in English sole liver composites resulted in few compounds being detected. Detection limits for these compounds typically ranged from 25 to 100 ug/kg wet weight, although detection limits for pesticides ranged from 100 to 200 ug/kg wet weight. Detected compounds included phenol, naphthalene, hexachlorobenzene (HCB), hexachlorobutadiene (HCBD), di-n-butyl phthalate, benzyl alcohol, and PCBs. In the 35 samples, phenol and di-n-butyl phthalate were detected only twice each, with no apparent relationship to liver condition. HCB (130-260 ug/kg wet weight) and HCBD (71-170 ug/kg wet weight) were detected only in fish livers from Hylebos Waterway. Each of these compounds was detected at similar concentrations in both normal and diseased liver samples from Hylebos Waterway.

Naphthalene was detected at concentrations of 30-240 ug/kg wet weight only in normal livers from Carr Inlet and several waterways. Benzyl alcohol was detected in 12 of the 35 samples at concentrations of 220 to 14,000 ug/kg wet weight.

Of the organic compounds, PCBs were the most frequently detected (all 35 samples) and were measured at the highest concentrations, ranging from 220 to 11,000 ug/kg wet weight (Table 4.14). When compared to concentrations from Carr Inlet, PCBs were clearly elevated in both normal and diseased livers from English sole in Commencement Bay waterways. Average concentrations in both diseased and normal livers from the waterways were typically about 2,000 ug/kg wet weight. Fish with normal livers, megalocytic hepatosis, neoplasms, and various other abnormalities all had similar PCB levels in their livers. Fish with multiple hepatic lesions from the waterways had the highest average (4,500 ug/kg wet weight) and maximum (11,000 ug/kg wet weight) liver PCB concentrations. Normal English sole collected from the Ruston-Pt. Defiance Shoreline had liver PCB levels that were intermediate between those measured in fish from the waterways and those from Carr Inlet.

These data indicate that sole in the waterways are accumulating higher levels of PCBs in their livers relative to reference levels in Puget Sound. Relatively high concentrations (about 2,000 ug/kg wet weight) were consistently measured in both normal and abnormal livers. Although the highest PCB levels occurred in fish with multiple hepatic lesions, there is no overall indication of higher PCB concentrations in livers of diseased fish.

The relationship between tissue contamination and fish histopathology was investigated further by evaluating the occurrences of liver lesions in the 85 English sole used for muscle tissue bioaccumulation studies. As was indicated in Section 3.6, few contaminants displayed elevated concentrations relative to reference conditions in Commencement Bay sole muscle samples. Moreover, several of the detected organic compounds were found at low levels in only a few fish from selected sites. PCBs, however, were detected in almost all English sole tested and were significantly elevated in several Commencement Bay waterways. PCBs also pose the greatest public

TABLE 4.14. TOTAL PCB CONCENTRATIONS (ug/kg wet weight) IN ENGLISH SOLE COMPOSITE LIVER SAMPLES

Liver Condition	Location	n	Mean	Range
Normal	Waterways	12	2,012	1,000-4,600
Normal	Carr Inlet	2	260	220-300
Normal	Ruston-Pt. Defiance	3	866	620-1,037
Neoplasms	Waterways	1	1,800	---
Megalocytic Hepatosis	Waterways	3	1,990	970-2,900
Multiple Lesions	Waterways	4	4,500	1,900-11,000
Various Abnormalities	Waterways	4	1,925	1,100-3,000

health risk of the contaminants bioaccumulated by Commencement Bay English sole. Therefore, data on PCB levels in muscle tissue were compared with liver histopathology results to determine whether muscle tissue from fish with liver lesions also had elevated contaminant levels.

The 75 English sole collected from Commencement Bay for bioaccumulation studies are categorized according to the occurrence of major hepatic lesion types in Table 4.15. For preneoplastic lesions and megalocytic hepatosis, lesion prevalences were lower in fish with muscle tissue PCB concentrations <100 ug/kg wet weight than in fish with PCB levels >100 ug/kg wet weight. However, statistical analyses using the G-test of all three lesion categories indicated that lesion prevalence was independent ($P>0.05$) of PCB levels. Thus, there is no clear relationship between uptake of PCBs and occurrence of liver lesions. English sole with all three major lesion types can have either low or high PCB concentrations in their muscle tissue.

Although aromatic hydrocarbons have been implicated as causative agents in the development of fish hepatic lesions (Malins et al. 1984), these compounds are rapidly metabolized and do not generally accumulate in fish muscle tissue. In this study, naphthalene was the only aromatic hydrocarbon measured at detectable levels in English sole muscle. Naphthalene was detected relatively infrequently and occurred consistently in high concentrations only in four English sole from Milwaukee Waterway. Therefore, the naphthalene data were not appropriate for statistical analyses of disease prevalence. Qualitative examination of the histopathological data indicates, however, that two of the four English sole from Milwaukee Waterway with high naphthalene concentrations also had megalocytic hepatosis. One of these sole also had hepatic neoplasms and preneoplastic lesions.

4.6.3 Summary

There were no generalized patterns of higher levels of contaminants in fish livers with serious lesions when compared to normal livers. Although fish with multiple hepatic lesions had the highest liver concentrations of PCBs, substantially elevated PCB levels occurred in both normal and abnormal livers in English sole from the waterways.

TABLE 4.15. OCCURRENCES OF MAJOR HEPATIC LESIONS RELATIVE TO MUSCLE TISSUE PCB LEVELS IN ENGLISH SOLE FROM COMMENCEMENT BAY

Muscle PCB Concentration (ug/kg wet weight)	Lesion Category: Neoplasm Yes	Neoplasm No	Preneoplastic Yes	Preneoplastic No	Megalocytic Hepatosis Yes	Megalocytic Hepatosis No
<100	1	31	3	29	1	31
100-399	0	30	5	25	5	25
≥400	1	12	2	11	2	11

5. PUBLIC HEALTH ASSESSMENT

5.1 INTRODUCTION

The results of this study and previous investigations have shown that various inorganic and organic contaminants are bioaccumulated by Commencement Bay fishes and shellfish. The objective of the public health assessment is to determine if there are significant health risks associated with consumption of fish and shellfish from Commencement Bay. This assessment used data on tissue concentrations of contaminants collected in 1984 as part of the bioaccumulation studies (see Section 3.6) and data on fish catch/consumption from a 1981 survey by the Tacoma-Pierce County Health Department.

Only one exposure route (i.e., eating non-salmonid fish, fish livers, and crabs from Commencement Bay) was considered in the assessment. Other possible exposure routes (e.g., drinking water, inhalation) were not considered.

English sole and crab were selected for these analyses because of their availability in the project area and because they live in close association with contaminated bottom sediments. Although English sole are not commonly caught by local fishermen, they were used as a conservative estimate of the maximum contaminant levels that would be expected to occur in edible fish tissues. Data from a previous study (Gahler et al. 1982) have shown that concentrations of PCBs and arsenic are two to three times higher in English sole than in commonly caught fish such as walleye pollack, hake, and cod.

The remainder of this section is a summary of the assessment of human health risks conducted for the Commencement Bay study. The detailed results are contained in a separate report prepared under the Commencement Bay project (Versar, Inc. 1985).

5.2 SUMMARY OF RESULTS

As indicated in Section 3.6, English sole and crabs from Commencement Bay contained higher concentrations and a wider variety of organic compounds than conspecifics from the Carr Inlet reference area. There was little difference between Commencement Bay and Carr Inlet in the concentrations of metals in fish and crab tissues.

Risk assessments for carcinogens and noncarcinogens were based on the range of fish consumption rates presented in Section 2.11. Of the total exposed population of 15,220 persons, only 30 persons experienced the maximum consumption rate of 1 lb/day. From the same population, 1,735 persons consumed 1 lb/mo. Approximately 82 percent of these exposed population (12,500 persons) consumed less than 1 lb/mo.

In subsequent discussions, individual carcinogenic risks are presented as a probability of contracting cancer resulting from the specified exposure.

These risks are presented as negative exponents, where, for example, 10^{-6} represents a 1 in 1 million chance of contracting cancer.

5.2.1 Carcinogens in Fish Muscle Tissue

At the maximum fish consumption rate of 1 lb/day, estimated individual lifetime risks would exceed 10^{-6} for six carcinogens (Table 5.1: PCBs, arsenic, hexachlorobenzene, hexachlorobutadiene, bis(2-ethylhexyl) phthalate, and tetrachloroethene. At this high consumption rate, individual risks would range from 10^{-5} to 10^{-3}. At a fish consumption rate of 1 lb/mo, only PCBs and arsenic would exceed the 10^{-6} risk level.

For a given consumption rate, estimated individual risks from consuming Commencement Bay fish muscle would exceed those for consuming Carr Inlet fish for three of the above six carcinogens: PCBs, bis(2-ethylhexyl) phthalate, and tetrachloroethene. Comparative risks for these compounds at the maximum 1 lb/day consumption rate are:

	Individual Risk	
Chemical	Commencement Bay	Carr Inlet
PCBs	$6x10^{-3}$	$1x10^{-3}$
bis(2-ethylhexyl) phthalate	$2x10^{-5}$	$3x10^{-6}$
Tetrachloroethene	$1x10^{-5}$	$3x10^{-6}$

Estimated individual risks from consuming fish from Commencement Bay and Carr Inlet for arsenic were similar, although Carr Inlet risks were slightly higher. At the maximum 1 lb/day ingestion rate, risks for arsenic would be: Commencement Bay, $4x10^{-4}$; Carr Inlet, $7x10^{-4}$.

Hexachlorobutadiene and hexachlorobenzene were detected in 2 of 15 English sole analyzed in Hylebos Waterway, but not in other areas. These compounds were present in the two Hylebos Waterway fish at concentrations near the lower limit of analytical detection. The estimated risk from eating these two fish was similar to the risk from eating fish from Carr Inlet since it was assumed that all contaminants were present in concentrations equal to the detection limit. Hylebos Waterway remains unique, however, with respect to the presence of these two chemicals.

Fish tissue concentrations and hence the associated risk for consuming fish varied somewhat among the Commencement Bay Waterways. For PCBs, the suspected carcinogen representing the greatest individual risk, fish consumed from City and Hylebos Waterways represented the greatest risk. For PCBs, risks associated with eating fish from Hylebos and City Waterways were about 10 times higher than those for fish from Carr Inlet. Risks associated with PCBs decreased with distance from City Waterway towards Pt. Defiance.

Estimated individual risks for all chemicals in the Pt. Defiance area were similar to those in the Carr Inlet reference area. For arsenic, the risks were similar throughout the project area at the reference area. Estimated risks for bis(2-ethylhexyl) phthalate ranged from $2x10^{-5}$ (City, Milwaukee, Ruston-Pt. Defiance Shoreline) to $3x10^{-6}$ (Hylebos Waterway and Carr Inlet) at the 1 lb/day consumption rate. Tetrachloroethene was only analyzed for in four areas. At the maximum consumption rate, estimated risks would range from $2x10^{-5}$ (St. Paul, Hylebos) to $3x10^{-6}$ (Carr Inlet).

TABLE 5.1. ESTIMATED INDIVIDUAL LIFETIME RISKS FOR ORGANIC COMPOUNDS IN FISH MUSCLE TISSUE

Chemical	Consumption Rate 1 lb/day	 1 lb/mo
PCB	6×10^{-3}	2×10^{-4}
Arsenic	4×10^{-4}	1×10^{-5}
Hexachlorobenzene	1×10^{-4}	4×10^{-6}
Hexachlorobutadiene	2×10^{-5}	7×10^{-7}
bis(2-ethylhexyl) phthalate	2×10^{-5}	6×10^{-7}
Tetrachloroethene	1×10^{-5}	5×10^{-7}

Hexachlorobutadiene and hexachlorobenzene were detected in fish muscle tissue only in Hylebos Waterway.

Estimated individual risks for two carcinogens found in the sediments but not detected in fish muscle tissue would exceed 10^{-6} under the conservative assumption that the compounds are present in fish muscle tissue at the detection limit: polynuclear aromatic hydrocarbons (PAH) and n-nitrosodipropylamine. At the 1 lb/day consumption rate, individual risks associated with these compounds would range from 3 to 4×10^{-3}. However, neither compound would be expected to be present in fish muscle tissue at concentrations near the detection limit.

A primary objective of the Commencement Bay project was to determine if any fish tissue contaminant resulted in the prediction of one or more excess cancer cases in the exposed population. This assessment was accomplished by applying the individual risks for each carcinogen to the exposed population estimated from the catch/consumption survey (see Section 2.11). The highest estimated incidence of cancer in the exposed population of 15,220 persons was between one and two cases in 70 years, attributable to PCBs causing cancer of the liver (Table 5.2). All available data indicate that the chemical associated with the highest individual lifetime cancer risk is PCBs; the next highest risk is attributable to arsenic. The maximum predicted cancer cases attributable to the two chemicals over a 70-yr exposure period are indicated in Table 5.2. Only for PCBs did the predicted number of cases exceed one, even with the conservative approach taken in this assessment (continuous exposure for 70 yr, etc.). As arsenic exposure is predicted to result in fewer than one case in 70 yr, and it ranked the second highest in individual risk, no other chemical is expected to produce cancer in the exposed population under the circumstances presented in this assessment.

5.2.2 Noncarcinogens in Fish Muscle Tissue

Three chemicals were present in fish muscle at levels that would cause exposure to exceed the Acceptable Daily Intake (ADI) at the 1 lb/day consumption rate: antimony, lead, and mercury.

Tissue concentrations of these chemicals were very similar among project areas and at the Carr Inlet reference site. Therefore, the ADIs would be exceeded at both Carr Inlet and Commencement Bay for the 1 lb/day consumption rate.

Limiting consumption of fish to one-half pound per day would result in exposure less than the ADI for all of these chemicals. However, health risks at this consumption rate would still exist due to the presence of carcinogens.

5.2.3 Carcinogens in Crab Muscle Tissue

For PCBs and arsenic, estimated individual risks from consuming crabs from Commencement Bay were approximately the same as those from eating fish. Bis(2-ethylhexyl)phthalate represented a higher risk in crabs than in fish. Average risks for Commencement Bay, based on a consumption rate of 1 lb/day of crab muscle, would be as follows:

TABLE 5.2. PROJECTED LIFETIME CANCER CASES FOR PCBs AND ARSENIC

Consumption Frequency (1 lb)	Fish Intake (g/day)	Exposure (mg/kg/day)	Individual Risk	Exposed Population	Predicted Cancer Cases
PCBs					
Daily	453.0	1.36×10^{-3}	5.90×10^{-3}	30	0.18
Weekly	64.7	1.94×10^{-4}	8.42×10^{-4}	1,005	0.85
Monthly	15.1	4.53×10^{-5}	1.97×10^{-4}	1,735	0.34
Bimonthly	7.4	2.22×10^{-5}	9.63×10^{-5}	1,111	0.11
Twice/yr	2.5	7.50×10^{-6}	3.26×10^{-5}	2,618	0.09
Yearly	1.2	3.60×10^{-6}	1.56×10^{-5}	8,721	0.14
TOTAL				15,220	1.69
Arsenic					
Daily	453.0	3.16×10^{-5}	4.42×10^{-4}	30	0.01
Weekly	64.7	4.51×10^{-6}	6.31×10^{-5}	1,005	0.06
Monthly	15.1	1.05×10^{-6}	1.47×10^{-5}	1,735	0.03
Bimonthly	7.4	5.16×10^{-7}	7.22×10^{-6}	1,111	0.01
Twice/yr	2.5	1.74×10^{-7}	2.44×10^{-6}	2,618	0.01
Yearly	1.2	8.37×10^{-8}	1.17×10^{-6}	8,721	0.01
TOTAL				15,220	0.13

PCBs	3×10^{-3}
Arsenic	2×10^{-4}
Bis(2-ethylhexyl)phthalate	3×10^{-6}

Risks for all other carcinogens were less than 10^{-6}. Only PCBs resulted in average individual risks from eating Commencement Bay crabs that were greater than the risks from eating Carr Inlet crabs. The average risk for Commencement Bay crabs due to PCBs was about three times the Carr Inlet risk. Within Commencement Bay, highest PCB risks were for crabs from Sitcum Waterway. The risks associated with bis(2-ethylhexyl) phthalate were higher from eating Carr Inlet crabs than Commencement Bay crabs.

5.2.4 Noncarcinogens in Crab Muscle

At the maximum consumption rate of 1 lb/day, calculated exposures would exceed the ADI for the following contaminants: antimony, lead, silver, zinc, and mercury. For these metals, the ADIs were exceeded for crabs from both Commencement Bay and Carr Inlet. For most of the metals, the differences between Carr Inlet and Commencement Bay were slight. The maximum difference between Commencement Bay and the reference area was for lead, where crabs from Sitcum Waterway exceeded the ADI by a factor of 4.2.

Limiting consumption of crabs from either Commencement Bay or Carr Inlet to 1 lb/wk or less would result in all noncarcinogenic exposures being below the ADI.

5.2.5 Consumption of Fish Livers

Twenty-one chemicals were detected in at least one fish liver composite sample from Commencement Bay. Four of the detected chemicals are considered to be carcinogens: PCBs, hexachlorobenzene, hexachlorobutadiene, and arsenic.

At the maximum consumption rate of 0.12 lb/day, consumption of PCBs in fish liver resulted in a predicted individual lifetime risk of 2×10^{-2}. This risk is higher than the corresponding risk from consuming PCBs in fish muscle tissue (6×10^{-3}) because of the much higher PCB levels in fish liver. The predicted risk level for PCBs in Commencement Bay fish livers is also about 15 times higher than the corresponding risk for fish livers from Carr Inlet.

Maximum predicted carcinogenic risks for hexachlorobenzene and hexachlorobutadiene in fish liver were about the same as the corresponding risks for fish muscle (10^{-4} and 10^{-5}, respectively). All other predicted carcinogenic risks were much lower than these levels.

These maximum predicted risks are associated with a high assumed consumption rate (i.e., eating almost 2 oz of liver every day). The predicted risks would be much lower for less frequent consumption of fish livers. This worst-case scenario was used, however, because of the absence of available information on fish liver consumption for Commencement Bay.

The ratios of exposure to ADI for all noncarcinogens present in fish livers from Commencement Bay were less than 0.1. Therefore, even at the maximum consumption rate of 0.12 lb/day, no human health effects attributable to these chemicals would be expected.

Of the chemicals detected in fish livers from Commencement Bay, PCBs pose the greatest potential risk to public health. Although the maximum predicted risk (10^{-2}) was associated with a high consumption rate, even much less frequent consumption of fish liver would result in a substantial predicted risk.

6.0 PRIORITIZATION OF PROBLEM AREAS AND CONTAMINANTS

6.1 INTRODUCTION

Results from previous sections on chemistry, toxicity, and biological effects are integrated in this section to identify and prioritize problem areas for source evaluation. The decision-making approach for the ranking of problem areas is presented in detail in Tetra Tech (1984a) and summarized in Figure 6.1. The first step of this procedure was to assemble "action assessment" matrices of the independent indicators used to characterize Commencement Bay sediments and biota. These data were compared among areas and evaluated for:

- The significance of each indicator relative to reference conditions
- The combination of significant indicators that characterized each area
- The relative magnitudes of significant indicators.

Two levels of spatial resolution of contaminant effects were provided by these matrices. First, average conditions were compared among the eight Commencement Bay study areas (i.e., the seven waterways and the Ruston-Pt. Defiance Shoreline). Second, average conditions were compared among segments within study areas to define general trends in the larger areas (Hylebos, Blair, and City Waterways, and the Ruston-Pt. Defiance Shoreline). Action-level guidelines were then applied to identify and rank study areas and segments of concern. A widespread problem or a "hot spot" of major significance occurred within each study area or segment of concern.

Using all available data [including acceptable historical data and data from the quantitative relationships (Section 4)] the spatial extent of each problem area was then defined. "Hot spots" of strictly local significance that were not reflected in average conditions at the study area or segment level were also defined. Problem areas were then ranked according to severity of observed contamination, toxicity, and biological effects. Potential problem chemicals were also identified and ranked. On the basis of these rankings, potential sources of characteristic chemicals in each problem area were evaluated (Section 7). Finally, priorities for remedial action were recommended (Section 8), based on the relative magnitude of problems, the spatial extent of the problem area, and the degree of confidence that sources of potential problem chemicals had been identified.

6.2 IDENTIFICATION OF PROBLEM AREAS

6.2.1 Action Assessment Matrices

The initial identification of problem areas was conducted using an action assessment matrix (Table 6.1). Average elevation above reference (EAR) values for different indicators of sediment contamination, sediment

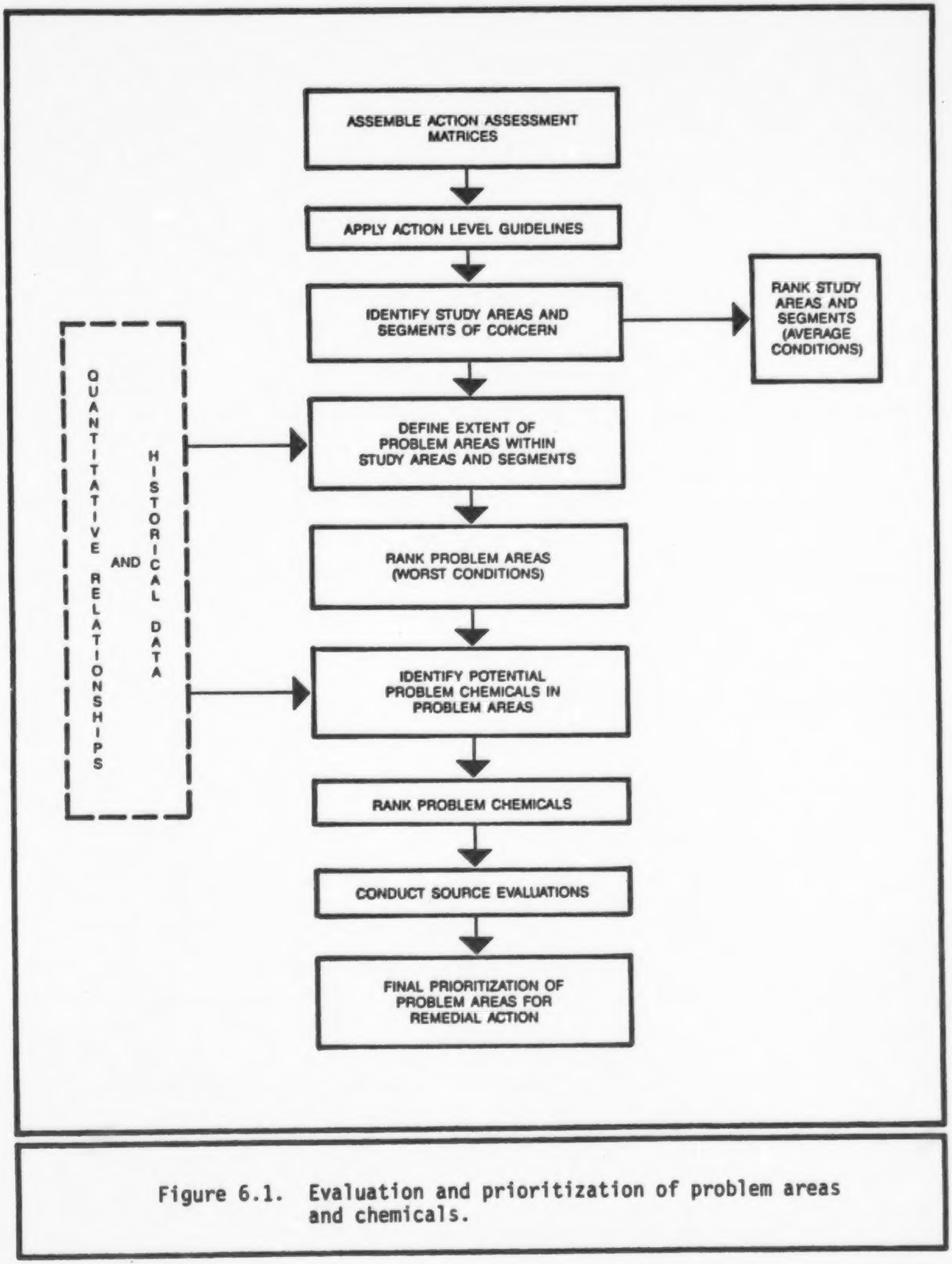

ASSEMBLE ACTION ASSESSMENT MATRICES
APPLY ACTION LEVEL GUIDELINES
IDENTIFY STUDY AREAS AND SEGMENTS OF CONCERN
RANK STUDY AREAS AND SEGMENTS (AVERAGE CONDITIONS)
QUANTITATIVE RELATIONSHIPS AND HISTORICAL DATA
DEFINE EXTENT OF PROBLEM AREAS WITHIN STUDY AREAS AND SEGMENTS
RANK PROBLEM AREAS (WORST CONDITIONS)
IDENTIFY POTENTIAL PROBLEM CHEMICALS IN PROBLEM AREAS
RANK PROBLEM CHEMICALS
CONDUCT SOURCE EVALUATIONS
FINAL PRIORITIZATION OF PROBLEM AREAS FOR REMEDIAL ACTION

Figure 6.1. Evaluation and prioritization of problem areas and chemicals.

TABLE 6.1. ACTION ASSESSMENT MATRIX OF SEDIMENT CONTAMINATION, SEDIMENT TOXICITY, AND BIOLOGICAL EFFECTS INDICES FOR COMMENCEMENT BAY STUDY AREAS

	STUDY AREA ELEVATIONS[a]								
VARIABLE	Hylebos	Blair	Sitcum	Milwaukee	St. Paul	Middle	City	Ruston	REFERENCE VALUE[b]
SEDIMENT CHEMISTRY									
Sb	10.	4.0	8.0	3.6	4.2	9.3	7.0	510.	110. ppb
As	12.	7.6	11.	3.6	2.2	9.6	7.5	620.	3370. ppb
Cd	2.4	1.9	2.8	1.7	1.7	2.8	5.5	27.	950. ppb
Cu+Pb+Zn	10.	4.8	24.	7.3	5.5	18.	22.	120.	35000. ppb
Hg	8.1	< 3.7	5.0	3.8	5.1	26.	10.	160.	40. ppb
Ni	1.4	0.7	0.6	0.8	0.8	0.7	1.4	2.8	1740. ppb
Phenol	< 6.4	< 5.2	4.3	< 2.1	12.	11.	9.4	4.5	< 33 ppb
Pentachlorophenol	1.7	< 2.3	< 2.1	< 0.90	U 1.9	5.6	< 1.9	< 1.0	U 33. ppb
LPAH	<45.	<28.	<68.	<60.	<73.	<110.	<120.	<87.	< 41. ppb
HPAH	<120.	<42.	<65.	<68.	<27.	< 97.	<140.	<85.	< 79. ppb
Chlor. benzenes	9.9	< 4.4	2.6	< 2.5	< 1.8	< 6.1	< 9.0	< 3.3	U 21. ppb
Chlor. butadienes	130.	< 2.7	< 2.4	< 1.2	< 1.3	< 6.8	< 1.9	< 1.7	U 62. ppb
Phthalates	4.0	< 2.6	< 0.58	< 0.66	< 0.56	< 5.1	< 7.1	4.5	< 280. ppb
PCBs	<48.	< 6.3	7.6	6.6	<17.	8.5	<12.	19.	< 6.0 ppb
4-Methylphenol	<7.3	<12.	10.	13.	1300.	< 33.	30.	<10.	< 13. ppb
Benzyl alcohol	5.0	< 2.2	2.4	3.4	< 6.7	3.3	4.7	< 1.2	U 10. ppb
Benzoic acid	< 0.7	< 3.2	< 0.5	< 0.7	< 1.0	U 0.1	< 1.6	< 0.5	< 140. ppb
Dibenzofuran	29.	25.	73.	59.	52.	80.	58.	<160.	U 3.7 ppb
Nitrosodiphenylamine	2.1	< 2.4	< 7.3	U 1.0	U 1.2	< 1.0	14.	<22.	U 4.1 ppb
Tetrachloroethene	12.	< 0.6	U 1.0	---	U 1.0	---	U 1.0	---	U 10. ppb
SEDIMENT TOXICITY									
Amphipod bioassay	2.1	1.9	2.9	2.4	4.8	1.4	2.7	3.9	9.3 %
Oyster bioassay	2.2	1.6	1.3	1.4	3.8	1.8	2.6	2.2	13.0 %
INFAUNA[c]									
Total benthos	1.2	1.0	0.7	0.8	1.9	1.5	0.7	0.6	d
Polychaetes	0.6	1.0	0.4	0.7	1.5	0.7	0.8	0.5	d
Molluscs	3.4	1.0	1.4	1.1	6.8	5.4	2.5	1.2	d
Crustaceans	1.5	1.0	3.8	0.4	1.0	4.6	1.2	0.7	d
FISH PATHOLOGY									
Lesion prevalence	3.6	2.5	3.5	3.7	2.7	5.7	1.7	2.1	6.7 %
FISH BIOACCUMULATION									
Copper	5.6	1.0	4.0	2.3	9.1	1.0	3.8	2.5	U 38. ppb
Mercury	1.5	0.93	0.80	1.6	0.76	1.3	0.82	0.96	U 55. ppb
Naphthalene	0.67	0.41	0.33	24.	0.19	0.19	4.1	0.19	< 54. ppb
Phthalates	21.	11.	0.53	3.6	0.41	0.41	6.7	5.6	< 74. ppb
PCBs[e]	9.2	7.0	4.8	2.8	1.1	4.7	9.8	1.9	< 36. ppb
DDE	3.8	5.1	3.3	3.4	1.7	1.7	6.2	2.9	< 1.8 ppb

[a] Boxed numbers represent elevations of chemical concentrations that exceed all Puget Sound reference area values, and statistically significant toxicity and biological effects at the P<0.05 significance level compared with reference conditions. The "U" qualifier indicates the chemical was undetected and the detection limit is shown. The "<" qualifier indicates the chemical was undetected at one or more stations. The detection limit is used in the calculations.

[b] Elevation above reference (EAR) values shown for each area are based on Carr Inlet reference values for each variable except for benthos (see footnote d).

[c] Infauna EAR are based on the elevation in biological effects represented by reductions in infaunal abundances relative to reference conditions. EAR for all other variables reflect an increase in the value of the variable at Commencement Bay compared with reference conditions.

[d] See Table 6.7 for a summary of reference benthic values used for groups of stations with similar grain size.

[e] Locations where PCB concentrations are significantly elevated also pose a significant health risk to the exposed population (see Table 6.8 guidelines).

toxicity, and biological effects (i.e., infaunal abundance, and English sole histopathology and muscle bioaccumulation) are summarized for each study area in Table 6.1. Reference values are also presented. Indicators are defined in the decision-making approach document (Tetra Tech 1984a). Original values for an indicator can be obtained by multiplying the EAR reported in the table by the appropriate reference value. Similar data averaged over study area segments in Hylebos, Blair, and City Waterways, and the Ruston-Pt. Defiance Shoreline are summarized in Tables 6.2-6.5. Waterway segments are arranged from the mouth (left) to the head (right). Ruston-Pt. Defiance Shoreline segments are arranged from Pt. Defiance (left) to the eastern shoreline off City Waterway (right). Histopathology and bioaccumulation data for English sole are not presented in these latter matrices, but are used only when averaged over an entire study area to indicate broad-scale biological effects. Mean reference values used to calculate benthic infauna EAR are presented in Table 6.6. These values differed among study areas and segments because of the grain size differences summarized in Table 6.7.

The average concentration of several organic compounds was significant (i.e., exceeded all Puget Sound reference conditions) in all study areas (Figure 6.1). Average metals contamination was significant in all areas except St. Paul Waterway. Blair and Milwaukee Waterways had the least chemical contamination, based on number and magnitude of significantly elevated chemical indices. Average sediment toxicity was statistically significant ($P<0.05$ experimentwise, t-test) in all areas except Middle Waterway. Average toxicity, as indicated by both kinds of bioassay, was significantly elevated only in Hylebos and City Waterway study areas. Elevations of benthic effects, as indicated by depressions abundances, were statistically significant ($P<0.05$ experimentwise, t-test) in Hylebos, Sitcum, St. Paul, Middle, and City Waterway.

The average prevalence of lesions (discussed in Section 3.5.6) was statistically significant ($P<0.05$ experimentwise, 2x2 contingency test) in all study areas except St. Paul and City Waterways, and the Ruston-Pt. Defiance Shoreline. Bioaccumulation in English sole muscle tissue was statistically significant ($P<0.05$) in all study areas except Middle Waterway.

The largest number of significant indicators was observed in Hylebos Waterway (significant EAR for 18 chemicals or groups of chemicals, and seven toxicity or biological effects indicators). The lowest number of significant indicators averaged over a study area was found in St. Paul Waterway (significant EAR for eight chemicals or groups of chemicals, and three significant toxicity or biological effects indicators).

Contamination, toxicity, and benthic effects were heterogeneous within the larger study areas (Tables 6.2-6.5). For example, although Hylebos Waterway as a whole exhibited the largest number of significant indicators and chemical contamination was evident throughout the waterway, there was no significant toxicity in Segments HYS3 or HYS4 and no significant benthic effects in Segments HYS3 or HYS6. In general, chemical contamination in Hylebos Waterway was most extensive at the head of the waterway, with additional

TABLE 6.2. ACTION ASSESSMENT MATRIX OF SEDIMENT CONTAMINATION, SEDIMENT TOXICITY, AND BIOLOGICAL EFFECTS INDICES FOR COMMENCEMENT BAY STUDY AREAS

	HYLEBOS SEGMENT ELEVATIONS[a]						
VARIABLE	HY-6	HY-5	HY-4	HY-3	HY-2	HY-1	REFERENCE VALUE[b]
SEDIMENT CHEMISTRY							
Sb	10.	4.5	6.8	8.3	8.2	25.	110. ppb
As	4.9	6.0	7.0	12.	19.	19.	3370. ppb
Cd	2.5	1.6	2.0	2.0	3.1	3.4	950. ppb
Cu+Pb+Zn	4.3	7.8	7.8	10.	14.	14.	35000. ppb
Hg	3.1	11.	7.0	6.6	8.0	6.9	40. ppb
Ni	0.7	1.2	1.1	1.4	2.3	1.6	1740. ppb
Phenol	5.9	< 4.7	3.4	< 5.0	< 4.4	<13.	< 33. ppb
Pentachlorophenol	< 2.1	< 1.8	< 2.4	<0.98	U 1.7	U 1.6	U 33. ppb
LPAH	<19.	<43.	<52.	<27.	<73.	<48.	< 41. ppb
HPAH	<19.	<58.	<99.	<68.	<220.	<260.	< 79. ppb
Chlor. benzenes	< 2.9	16.	< 7.6	< 5.9	< 6.8	< 2.2	U 21. ppb
Chlor. butadienes	<11.	<290.	110.	55.	80.	<11.	U 62. ppb
Phthalates	<11.	< 2.6	< 2.1	< 1.5	< 6.3	< 4.0	< 280. ppb
PCBs	<10.	<49.	<23.	44.	110.	<26.	U 6. ppb
4-Methylphenol	15.	< 4.6	18.	< 4.6	< 5.0	6.8	< 13. ppb
Benzyl alcohol	6.4	< 5.3	3.5	< 3.0	< 9.8	< 1.8	U 10. ppb
Benzoic acid	< 0.6	< 0.6	< 0.5	< 0.6	< 1.5	< 0.3	< 140. ppb
Dibenzofuran	14.	33.	34.	18.	42.	26.	U 3.7 ppb
Nitrosodiphenylamine	U 1.2	< 1.4	< 6.8	< 3.5	U 1.2	U 1.2	U 4.1 ppb
Tetrachloroethene	---	< 1.8	---	3.3	2.2	5.0	U 10. ppb
SEDIMENT TOXICITY							
Amphipod bioassay	1.7	2.4	2.1	0.9	2.7	1.6	9.3 %
Oyster bioassay	2.0	1.9	1.8	1.8	2.5	2.9	13.0 %
INFAUNA[c]							
Total benthos	0.6	1.2	3.5	0.7	2.9	1.2	d
Polychaetes	0.4	0.6	1.4	0.3	1.6	0.6	d
Molluscs	0.8	4.7	44.	4.4	7.3	3.3	d
Crustaceans	0.3	1.7	14.	0.7	2.8	2.2	d

[a] See Table 6.1 for footnotes.

TABLE 6.3. ACTION ASSESSMENT MATRIX OF SEDIMENT CONTAMINATION, SEDIMENT TOXICITY, AND BIOLOGICAL EFFECTS INDICES FOR COMMENCEMENT BAY STUDY AREAS

	BLAIR SEGMENT ELEVATIONS[a]				
VARIABLE	BL-S4	BL-S3	BL-S2	BL-S1	REFERENCE VALUE[b]
SEDIMENT CHEMISTRY					
Sb	3.9	2.5	5.1	4.1	110. ppb
As	3.2	3.4	8.9	11.	3370. ppb
Cd	2.5	< 2.3	2.2	2.0	950. ppb
Cu+Pb+Zn	2.5	3.1	5.6	5.6	35000. ppb
Hg	1.5	< 2.4	4.6	3.6	40. ppb
Ni	0.7	0.7	0.7	0.8	1740. ppb
Phenol	2.6	< 5.9	< 5.0	< 4.4	< 33. ppb
Pentachlorophenol	U 2.0	< 3.0	< 2.4	< 1.1	U 33. ppb
LPAH	< 6.3	<26.	<32.	<23.	< 41. ppb
HPAH	< 3.7	<35.	<45.	<45.	< 79. ppb
Chlor. benzenes	U 1.4	< 2.7	< 6.8	< 1.8	U 21. ppb
Chlor. butadienes	< 1.4	< 3.7	< 2.4	U 1.7	U 62. ppb
Phthalates	< 5.8	< 1.4	< 2.8	< 3.7	< 280. ppb
PCBs	1.3	< 5.6	< 6.6	< 6.6	U 6. ppb
4-Methylphenol	8.0	<17.	14.	< 9.0	< 13. ppb
Benzyl alcohol	6.1	< 2.2	< 2.3	< 2.0	U 10. ppb
Benzoic acid	< 0.3	< 1.4	< 5.7	< 0.7	< 140. ppb
Dibenzofuran	5.2	26.	28.	19.	U 3.7 ppb
n-Nitrosodiphenylamine	U 1.2	< 1.0	< 4.0	< 1.4	U 4.1 ppb
Tetrachloroethene	---	---	U 1.0	U 0.5	U 10. ppb
SEDIMENT TOXICITY					
Amphipod bioassay	---	1.7	2.1	1.9	9.3 %
Oyster bioassay	---	1.6	1.6	1.4	13.0 %
INFAUNA[c]					
Total benthos	---	1.0	1.0	1.0	d
Polychaetes	---	1.0	1.0	1.0	d
Molluscs	---	1.0	1.0	1.0	d
Crustaceans	---	1.0	1.0	1.0	d

[a] See Table 6.1 for footnotes.

TABLE 6.4. ACTION ASSESSMENT MATRIX OF SEDIMENT CONTAMINATION, SEDIMENT TOXICITY, AND BIOLOGICAL EFFECTS INDICES FOR COMMENCEMENT BAY STUDY AREAS

	CITY SEGMENT ELEVATIONS[a]			
VARIABLE	CI-S3	CI-S2	CI-S1	REFERENCE VALUE[b]
SEDIMENT CHEMISTRY				
Sb	4.9	5.4	10.	110. ppb
As	5.6	6.8	4.9	3370. ppb
Cd	3.8	6.5	2.5	950. ppb
Cu+Pb+Zn	10.	28.	26.	35000. ppb
Hg	6.1	6.8	3.1	40. ppb
Ni	0.9	1.5	0.7	1740. ppb
Phenol	11.	<10.	8.7	< 33. ppb
Pentachlorophenol	< 1.8	2.1	< 1.9	U 33. ppb
LPAH	<120.	<110.	<120.	< 41. ppb
HPAH	130.	160.	140.	< 79. ppb
Chlor. benzenes	< 3.6	27.	< 7.5	U 21. ppb
Chlor. butadienes	< 2.4	< 0.8	< 2.0	U 62. ppb
Phthalates	< 2.7	< 9.2	< 9.	< 280. ppb
PCBs	< 7.9	20.	12.	< 6. ppb
4-Methylphenol	18.	45.	< 41.	< 13 ppb
Benzyl alcohol	3.0	U 1.0	6.2	U 10. ppb
Benzoic acid	< 1.5	< 0.2	< 1.8	< 140. ppb
Dibenzofuran	52.	72.	58.	U 3.7 ppb
n-Nitrosodiphenylamine	U 1.5	32.	<15.	U 4.1 ppb
Tetrachloroethene	---	U 1.0	U 1.0	U 10. ppb
SEDIMENT TOXICITY				
Amphipod bioassay	2.6	1.5	3.2	9.3 %
Oyster bioassay	2.0	2.5	3.0	13.0 %
INFAUNA[c]				
Total benthos	1.0	6.8	0.5	d
Polychaetes	1.1	4.6	0.5	d
Molluscs	1.0	24.2	7.7	d
Crustaceans	0.5	6.1	2.5	d

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[a] See Table 6.1 for footnotes.

TABLE 6.5 ACTION ASSESSMENT MATRIX OF SEDIMENT CONTAMINATION, SEDIMENT TOXICITY, AND BIOLOGICAL EFFECTS INDICES FOR COMMENCEMENT BAY STUDY AREAS

	RUSTON SEGMENT ELEVATIONS[a]			
VARIABLE	RS-S3	RS-S2	RS-S1	REFERENCE VALUE[b]
SEDIMENT CHEMISTRY				
Sb	140.	1100.	8.6	110. ppb
As	120.	1400.	5.7	3370. ppb
Cd	6.2	58.	1.8	950. ppb
Cu+Pb+Zn	42.	260.	6.1	35000. ppb
Hg	6.9	370.	5.8	40. ppb
Ni	1.1	4.9	1.2	1740. ppb
Phenol	1.4	5.5	4.5	< 33. ppb
Pentachlorophenol	U 1.1	< 1.1	< 0.9	U 33. ppb
LPAH	< 3.5	<150.	<51.	< 41. ppb
HPAH	6.4	130.	<68.	< 79. ppb
Chlor. benzenes	U 1.4	< 4.1	< 3.0	U 21. ppb
Chlor. butadienes	< 1.5	< 2.1	< 1.3	U 62. ppb
Phthalates	< 2.4	< 6.9	< 3.0	< 280. ppb
PCBs	< 1.9	41.	< 2.4	U 6. ppb
4-Methylphenol	U 0.8	< 7.8	<16.	< 13. ppb
Benzyl alcohol	U 1.0	< 1.2	< 1.8	U 10. ppb
Benzoic acid	U 0.2	< 0.8	< 0.2	< 140. ppb
Dibenzofuran	< 3.0	<160.	<36.	U 3.7 ppb
n-Nitrosodiphenylamine	< 5.5	<22.	U 0.9	U 4.1 ppb
Tetrachloroethene	---	---	---	U 10. ppb
SEDIMENT TOXICITY				
Amphipod bioassay	2.0	6.5	2.5	9.3 %
Oyster bioassay	1.1	3.2	1.8	13.0 %
INFAUNA[c]				
Total benthos	---	2.2	0.4	d
Polychaetes	---	1.6	0.3	d
Molluscs	---	14.6	0.6	d
Crustaceans	---	2.0	0.4	d

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[a] See Table 6.1 for footnotes.

TABLE 6.6. MEAN REFERENCE VALUES USED TO CALCULATE ELEVATIONS ABOVE REFERENCE FOR BENTHIC INFAUNA

Reference Group[a]	Stations Included	Percent Fines[b]	Mean Benthic Invertebrate Abundance/m^2			
			Total	Polychaetes	Molluscs	Crustaceans
A	BL-11,BL-21 BL-31	55-64	10,983	4,254	6,049	635
B	BL-13	84	10,604	4,400	5,933	217
C	CR-11,CR-12 CR-13,CR-14	4-21	3,683	1,644	1,016	934
D	BL-28,BL-11 BL-21,BL-31	37-64	9,013	3,452	4,980	529
E	BL-28,BL-11 BL-21,BL-31 CR-11,CR-12 CR-13,CR-14	4-84	9,331	3,642	5,171	467
F	BL-11,BL-21 BL-31,BL-13	55-84	10,889	4,291	6,020	530

[a] Different groupings of the reference stations in Table 3.24 were formed to represent the different benthic habitats included in Commencement Bay study areas and segments.

[b] The range of percent fine-grained material (i.e., silt and clay) present in sediments sampled at the reference stations.

TABLE 6.7. IDENTIFICATION OF REFERENCE GROUPS USED TO CALCULATE BENTHIC ABUNDANCE ELEVATIONS ABOVE REFERENCE FOR STUDY AREAS AND SEGMENTS

Study Area/ Segment[a]	Percent Fine-Grained Material[b]	Reference Group[c]
Hylebos	6 - 86	E
Sitcum	76 - 81	F
Milwaukee	85 - 89	B
St. Paul	26 - 67	D
Middle	56	A
City	28 - 80	D
Ruston-Pt. Defiance	3 - 33	C
HYS1	48 - 79	D
HYS2	76 - 86	F
HYS3	61	A
HYS4	61	A
HYS5	6 - 78	D
HYS6	86	B
CIS1	39 - 78	D
CIS2	74	A
CIS3	28 - 80	D
RSS1	13 - 29	C
RSS2	3 - 33	C

[a] Blair Waterway and Segments BLS1, BLS2, and BLS3 are not listed because their component stations (except BL-25) were considered representative of reference conditions. No benthic data were collected for BLS4 or RSS3

[b] The range of percent fine-grained material (i.e., silt and clay) present in sediments sampled in each study area or segment.

[c] Reference groups are defined in Table 6.6.

high values for selected chemicals in Segment HYS5 near the mouth of the waterway.

Relatively lower levels of chemical contamination were observed in the adjacent Blair Waterway. These lower contaminant levels corresponded to a lack of significant toxicity or benthic effects indicators when averaged over any segment (Table 6.3). Within City Waterway (Table 6.4), contamination, toxicity, and benthic effects were highest near the head and within the Wheeler-Osgood branch of the waterway. The mouth of City Waterway was comparable in number and magnitude of significant indicators with Segment RSS1 along the eastern Ruston-Pt. Defiance Shoreline (Table 6.5). The extreme metals contamination and high level of organic compound contamination within Segment RSS2 corresponded with the largest number and highest average magnitude of toxicity and benthic effects indicators along the Ruston-Pt. Defiance Shoreline.

6.2.2 Application of Action Levels to Determine Problem Areas

Action-level guidelines are summarized in Table 6.8. A problem area requiring further evaluation is identified when values for three or more indices are significantly elevated. Using this guideline, problem areas were indicated within all Commencement Bay study areas and segments shown in Tables 6.1-6.5. Several of the segments within the larger study areas met this criterion only when study area-wide values for English sole pathology and bioaccumulation were considered. According to Table 6.8 guidelines, significant bioaccumulation of PCBs in Hylebos, Blair, Sitcum, and City Waterways may warrant source identification based solely on the prediction of possible significant health effects.

Six segments within the larger study areas had significant EAR for all three of the site-specific indicators (contamination, sediment toxicity, and benthic effects) including:

- Segments HYS1, HYS2, and HYS5 in Hylebos Waterway
- Segments CIS1 and CIS2 in City Waterway
- Segment RSS2 along the Ruston-Pt. Defiance Shoreline.

A problem area was also indicated in Segment HYS4 of Hylebos Waterway based on mollusc abundances being depressed by greater than 95 percent relative to reference conditions (i.e., EAR >20). According to guidelines in Table 6.8, this condition indicated a problem area regardless of the values for other indicators.

6.2.3 Ranking of Study Areas and Segments

As discussed, average conditions in all study areas and segments exceeded the thresholds required for further definition of problem areas for source evaluation. Criteria presented in Table 6.9 were applied to action assessment matrices (Tables 6.1-6.5) to rank study areas and segments. These rankings were based on average conditions in each area, and provide an overview of the relative contamination and contaminant effects throughout Commencement Bay. This relative ranking process was independent from the action guidelines

TABLE 6.8. ACTION-LEVEL GUIDELINES

Condition Observed	Threshold Required for Action
I. Any **THREE OR MORE** significantly elevated indices[a]	Threshold exceeded, continue with definition of problem area
II. **TWO** significantly elevated indices	
1. Sediments contaminated, but below 80th percentile **PLUS**: Bioaccumulation without an increased human health risk relative to that at the reference area, **OR** Sediment toxicity with less than 50 percent mortality or abnormality, **OR** Major benthic invertebrate taxon depressed, but by less than 95 percent.	No immediate action. Recommend site for future monitoring.
2. Sediments contaminated but below 80th percentile **PLUS** elevated fish pathology	Threshold for problem area definition exceeded if elevated contaminants are considered to be biologically available. If not, recommend site for future monitoring.
3. Any **TWO** significantly elevated indices, but **NO** elevated sediment contamination	Conduct analysis of chemistry to distinguish site from adjacent areas. If test fails, no immediate action warranted. Otherwise, threshold exceeded for characterization of problem area. Re-evaluate significance of chemical indicators.
III. **SINGLE** significantly elevated index	
1. Sediment contamination	If magnitude of contamination exceeds the 80th percentile for all study areas, recommend area for potential source evaluation at a low priority relative to areas exhibiting contamination and effects.

TABLE 6.8. (Continued)

2. Bioaccumulation	Increased human health threat, defined as: Prediction of ≥ 1 additional cancer cases in the exposed population for significantly elevated carcinogens, **OR** For noncarcinogens, exceedance of the acceptable daily intake value is required.
3. Sediment toxicity	Greater than 50 percent response (mortality or abnormality).
4. Depressed benthic abundance	95 percent depression or greater of a major taxon (equals an EAR of 20 or greater).
5. Fish pathology	Insufficient as a single indicator. Recommend site for future monitoring. Check adjacent areas for significant contamination, toxicity, or biological effects.

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[a] Combinations of significant indices are from independent data types (i.e. sediment chemistry, bioaccumulation, sediment toxicity, benthic infauna, fish pathology).

Significant indices are defined as follows:

Sediment chemistry = chemical concentration at study site exceeds highest value observed at any Puget Sound reference area.

Sediment toxicity, benthic abundance, bioaccumulation, and pathology = statistically significant ($P < 0.05$) difference between study area and reference area.

TABLE 6.9. SUMMARY OF RANKING CRITERIA FOR SEDIMENT CONTAMINATION, TOXICITY, AND BIOLOGICAL EFFECTS INDICATORS

Indicator	Criteria	Score
Total Metals Contamination	Concentration not significant	0
	Significant; EAR <10	1
	Significant; EAR 10-<50	2
	Significant; EAR 50-<100	3
	Significant; EAR >100	4
Total Organic Compound Contamination	Concentration not significant	0
	Significant; EAR <10	1
	Significant; EAR 10-<100	2
	Significant; EAR 100-<1000	3
	Significant; EAR >1000	4
Toxicity[a]	No significant bioassay response	0
	Amphipod OR oyster bioassay significant	2
	Amphipod AND oyster bioassays significant	3
	>50 percent response in EITHER bioassay	4
Macroinvertebrates (Abundance)[b]	No significant depressions	0
	1 significant depression	1
	2 significant depressions	2
	≥ 3 significant depressions	3
	≥ 1 taxon with ≥ 95% depression	4
Bioaccumulation (Fish Muscle)	No significant chemicals	0
	1 significant chemical	1
	2 significant chemicals	2
	≥ 3 significant chemicals	3
	Significant bioaccumulation of ≥ 1 chemical posing a human health threat[c]	4
Fish Pathology (Liver Lesions)[d]	No significant lesion types	0
	1 significant lesion type	1
	2 significant lesion types	2
	≥ 3 significant lesion types	3
	≥ 5% prevalence of hepatic neoplasms	4
Maximum Possible Score		24

[a] Toxicity based on amphipod mortality and oyster larvae abnormality bioassays.

[b] Taxa considered were total benthic taxa, Polychaeta, Mollusca, and Crustacea.

[c] As defined in Table 6.8: Action-Level Guidelines.

[d] Lesions considered were hepatic neoplasms, preneoplastic nodules, megalocytic hepatosis, and nuclear pleomorphisms.

used to define problem areas. A separate ranking of defined problem areas within each study area is presented in Section 6.4. That ranking is based on the maximum contamination and effects observed in each problem area.

Results of the ranking of study areas and segments for chemical contamination are given in Table 6.10. Scores noted in Table 6.9 were based solely on the magnitude of chemical contamination. The scale used for metals differed from that for organic compounds to provide better resolution of the typically smaller range in metals concentrations among waterways compared with that of organic compounds. Separate rankings are given in Table 6.10 based on the average EAR of metals, organic compounds, and the sum of metals and organic compounds. When study areas or segments had the same score for the magnitude of chemical contamination, the areas were further prioritized by the number of chemicals with significant EAR. For example, the average metals contamination in sediments from Hylebos, Middle, City, and Sitcum Waterways was of the same order of magnitude (i.e., EAR 10-<50) resulting in a score of 2 for each waterway. Of these waterways, Hylebos Waterway had the largest number of metals or groups of metals (5) with significant EAR and Sitcum Waterway had the least (3). Although Middle and City Waterways had the same score for metals contamination and the same number of metals with significant EAR (4), Middle Waterway was ranked higher because the absolute magnitude of contamination in Middle Waterway was higher than that in City Waterway. This sequential evaluation of chemical contamination was used to rank all study areas and segments relative to each other. Segment RSS2 along the Ruston-Pt. Defiance Shoreline had the highest overall level of contamination, while Blair Waterway, Milwaukee Waterway, and the eastern shoreline of the Ruston-Pt. Defiance Shoreline had the lowest overall levels of contamination.

A separate ranking of study areas and segments by the average number and magnitude of statistically significant ($P<0.05$) sediment toxicity and biological effects is given in Table 6.11. For toxicity and biological effects indices, areas were scored primarily by the number of significant indicators. As shown in Table 6.9, the highest score of 4 in the toxicity and biological effects indices was assigned for special concerns related to the severity of the toxic response or biological effect. No attempt was made to resolve tied scores among segments in Table 6.11 as was done for chemical contamination ranked in Table 6.10. Based on this scoring, Sitcum Waterway was ranked highest of all study areas, primarily because PCB bioaccumulation posed potential health concerns and hepatic neoplasms exceeded 5 percent prevalence. Sitcum Segment SIS1 and Hylebos Segment HYS2 ranked the highest for toxicity and biolgical effects on a segment basis. Average conditions along the Ruston-Pt. Defiance Shoreline ranked lowest among study areas, and Segments RSS1 and RSS3 ranked lowest among segments. When contributions from fish pathology and bioaccumulation indices were removed, Hylebos and City Waterways ranked the highest among study areas and also contained the highest ranked segments for combined toxicity and benthic effects.

Scores for study area segments based on the maximum observed values at any station within the segment for contamination, sediment toxicity, and benthic effects indices are listed in Table 6.12. Maximum observed conditions within each segment were used for scoring the site-specific indices so that worst-case conditions of problem areas within each segment

TABLE 6.10. RANKING OF STUDY AREAS AND SEGMENTS BY AVERAGE MAGNITUDE AND NUMBER OF SIGNIFICANT SEDIMENT CONTAMINANTS

Total Metals[a]			Total Organic Compounds[a]			Total Chemicals[a]		
Area or Segment	Number of Significant Metals	Score	Area or Segment	Number of Significant Compounds	Score	Area or Segment	Number of Significant Chemicals	Score
Ruston	6	4	St. Paul	7	4	Ruston	16	7
Hylebos	5	2	Hylebos	13	3	Hylebos	18	5
Middle	4	2	City	12	3	City	16	5
City	4	2	Middle	10	3	Middle	14	5
Sitcum	3	2	Ruston	10	3			
						Sitcum	13	4
Blair	1	1				St. Paul	7	4
Milwaukee	1	1	Blair	11	2			
			Sitcum	10	2	Blair	12	3
St. Paul	0	0	Milwaukee	7	2	Milwaukee	8	3
RSS2	6	4	SPS1	7	4	RSS2	16	7
RSS3	5	4						
			CIS1	12	3	HYS1	15	5
HYS1	5	2	HYS2	11	3	HYS2	15	5
MDS1	4	2	HYS5	11	3	CIS1	15	5
CIS2	4	2	HYS4	11	3	CIS2	14	5
HYS2	4	2	HYS1	10	3	MDS1	14	5
SIS1	3	2	RSS2	10	3	HYS5	14	5
CIS1	3	2	CIS2	10	3	RSS3	7	5
HYS3	3	2	MDS1	10	3			
HYS5	3	2	CIS3	9	3	HYS4	14	4
BLS1	1	2				SIS1	13	4
			BLS2	12	2	HYS3	13	4
HYS4	3	1	SIS1	10	2	CIS3	12	4
CIS3	3	1	HYS3	10	2	BLS1	9	4
HYS6	2	1	HYS6	10	2	SPS1	7	4
BLS2	2	1	BLS3	9	2			
RSS1	2	1	BLS1	8	2	BLS2	14	3
MIS1	1	1	MIS1	7	2	HYS6	12	3
BLS4	1	1	RSS1	6	2	BLS3	10	3
BLS3	1	1				MIS1	8	3
						RSS1	8	3
			BLS4	5	1			
SPS1	0	0	RSS3	2	1	BLS4	6	2

[a] Number of significant chemicals (metals or organic compounds) includes individual and groups of chemicals listed in the action assessment matrices (Tables 6.1-6.5). Total chemicals are the sum of metals and organic compound scores. Scores are defined in Table 6.9.

TABLE 6.11. RANKING OF STUDY AREAS AND SEGMENTS BY THE AVERAGE MAGNITUDE OF SEDIMENT TOXICITY AND BIOLOGICAL EFFECTS

	Score[a]				
Area or Segment	Sediment Toxicity	Macro-invertebrates	Muscle Bioaccumulation	Liver Pathology	Total
Sitcum	2	1	4	4	11
Hylebos	3	1	4	1	9
City	3	1	4	0	8
Blair	2	0	4	1	7
Middle	0	2	0	4	6
Milwaukee	2	0	2	1	5
St. Paul	2	1	1	0	4
Ruston	2	0	1	0	3
HYS2	3	3	4	1	11
SIS1	2	1	4	4	11
CIS2	2	4	4	0	10
HYS4	0	4	4	1	9
HYS5	3	1	4	1	9
HYS1	2	1	4	1	8
CIS1	2	2	4	0	8
HYS6	2	0	4	1	7
CIS3	3	0	4	0	7
RSS2	4	2	1	0	7
MDS1	0	2	0	4	6
HYS3	0	0	4	1	5
MIS1	2	0	2	1	5
BLS1	0	0	4	1	5
BLS2	0	0	4	1	5
BLS3	0	0	4	1	5
SPS1	2	1	1	0	4
BLS4	--[b]	--[b]	4	0	4
RSS1	2	0	1	0	3
RSS3	0	--[b]	1	0	1

[a] Scores are defined in Table 6.9.

[b] No data available.

TABLE 6.12. RANKING OF STUDY AREA SEGMENTS BY MAXIMUM OBSERVED SEDIMENT CONTAMINATION, TOXICITY, AND BIOLOGICAL EFFECTS

	Maximum Chemical Score[a]			Maximum Toxicity/Effects Score[a]					
Segment	Metals	Organic Compounds	Total	Bioassay	Benthos	Muscle Bioaccum	Liver Pathology	Total	TOTAL SCORE[a]
HYS1	2	3	5	2	4	4	1	11	16
HYS2	2	3	5	3	4	4	1	12	17
HYS3	2	3	5	0	0	4	1	5	10
HYS4	2	2	4	0	4	4	1	9	13
HYS5	2	4	6	2	1	4	1	8	14
HYS6	2	2	4	0	0	4	1	5	9
BLS1	2	3	5	0	0	4	1	5	10
BLS2	2	3	5	2	0	4	1	7	12
BLS3	1	2	3	0	0	4	1	5	8
BLS4	1	2	3	--[b]	--[b]	4	1	5	8[c]
SIS1	2	3	5	2	1	4	4	11	16
MIS1	1	3	4	2	0	2	1	5	9
SPS1	2	4	6	4	4	1	0	9	15
MDS1	3	3	6	0	0[d]	0	4	4	10
CIS1	3	3	6	4	4	4	0	12	18
CIS2	2	3	5	2	4	4	2	12	17
CIS3	2	2	4	3	0	4	0	7	11
RSS1	2	3	5	3	0	1	0	4	9
RSS2	4	3	7	4	4	1	0	9	16
RSS3	4	2	6	2	--[b]	1	0	3	9

[a] Segments defined for data analysis were scored by the maximum observed level of contamination, toxicity, or benthic effects at any station within the segment. Bioaccumulation and pathology scores reflect average waterway conditions only. Scores are defined in Table 6.9.

[b] No data available.

[c] Based on partial set of toxicity/effects indicators

[d] Benthic depressions were significant (rank=2) for Station MD-12 in Middle Waterway when tested among waterways, but not among all stations because of the effect of multiple comparisons on the critical t-value for the respective significance tests (i.e., waterway versus station level).

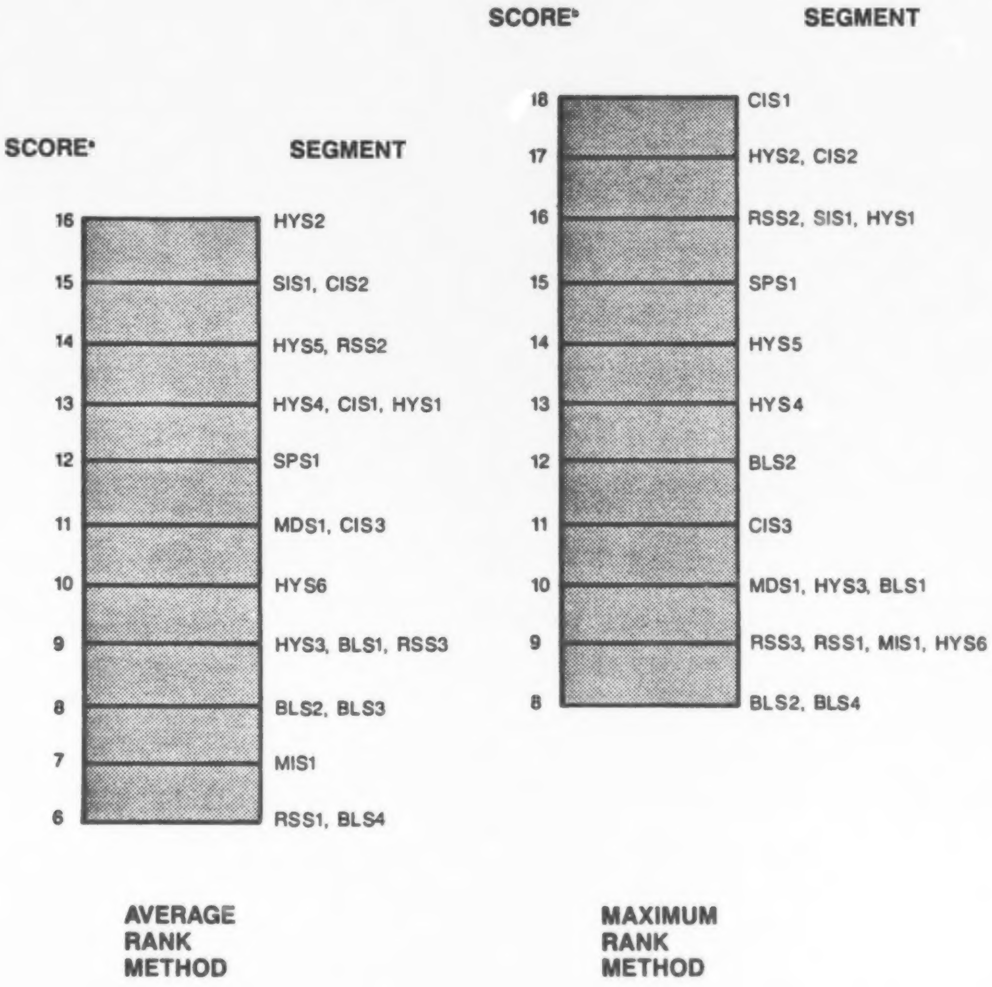
were considered. Scores for fish liver pathology and muscle bioaccumulation in Table 6.12 still reflect the average conditions observed throughout each study area. Scores for all five indicators are summed in Table 6.12 by segment to combine information for all available indicators. Segments are listed in Table 6.12 in geographic order rather than rank order to facilitate comparisons of conditions within a study area and between adjacent study areas.

After segments were prioritized according to average conditions (Tables 6.10, 6.11) and worst-case conditions (Table 6.12), results of the two methods were compared (Figure 6.2). Selected segments in Hylebos, Sitcum, and City Waterways and Segment RSS2 along the Ruston-Pt. Defiance Shoreline scored high by both methods. Milwaukee Waterway (MIS1), Blair Waterway segments, and Segment RSS1 on the eastern Ruston-Pt. Defiance Shoreline scored low by both methods.

6.3 SPATIAL EXTENT AND RANKING OF PROBLEM AREAS

Although chemical contamination data are available for all sediment samples collected, toxicity and macroinvertebrate abundance data are available only for some of the samples. The chemical data set is therefore the most useful for defining the spatial extent of problem areas, and was used to delineate the areas indicated in Table 6.13. All available data were used, including predictions of problem sediments based on sediment chemistry at non-biological stations and quantitative relationships (Section 4) that defined apparent effect thresholds for chemicals. Segments containing each problem area were ranked according to the "maximum" score for worst-case conditions in the segment (Table 6.13). The top eight problem areas all exhibited significant contamination, sediment toxicity, and benthic effects, in addition to having at least one significant indicator of fish pathology or bioaccumulation. The lowest ranking problem areas were contained in segments that did not exhibit significant sediment toxicity or benthic effects. Based solely on quantitative relationships, significant toxicity or benthic infaunal effects would be predicted at the stations indicated in Table 6.13 if biological data were collected.

The spatial extent and general priority for source evaluation of all problem areas identified in Commencement Bay are summarized in Figure 6.3. Problem areas defined only by mid-channel stations in the current study were assumed to extend from shoreline to shoreline, unless historical data indicated otherwise (e.g., nearshore historical samples were uncontaminated). At the highest priority sites, at least four indicators were significant, including all three site-specific indicators. Eight problem areas received highest priority for source evaluation, including three within Hylebos Waterway, two within City Waterway, and one within each of Sitcum and St. Paul Waterways and along the Ruston-Pt. Defiance Shoreline. The second priority sites are "hot spots" where chemical contamination exceeded an "apparent effect threshold" (AET), and both bioassays were significant or multiple benthic depressions were observed within the problem area. Four problem areas received second priority for source evaluation, including one each within Hylebos, Middle, and City Waterways, and at Station RS-13 along the eastern Ruston-Pt. Defiance Shoreline.



[a]SCORES ARE SUMS FOR CHEMICAL AND BIOLOGICAL INDICATORS FROM TABLES 6.10 AND 6.11

[b]SCORES ARE SUMMARIZED IN TABLE 6.12

Figure 6.2. Relative ranking of study area segments by average and maximum observed contamination, toxicity, and biological effects.

TABLE 6.13. DEFINITION AND RELATIVE RANKING OF PROBLEM AREAS

Segment Containing Problem Area[a]	Total Contaminant-Toxcity-Effects Score[b]	Stations Included in Problem Area[c]
CIS1	18	CI-11,CI-12,CI-13,CI-14,CI-15,CI-18[d]
HYS2	17	HY-20,HY-21,HY-22,HY-23
CIS2	17	CI-02,CI-16
RSS2	16	RS-03,RS-16,RS-17,RS-18,RS-19,RS-20,RS-21
SIS1	16	SI-11,SI-12,SI-13,SI-14,SI-15
HYS1	16	HY-11,HY-12,HY-13,HY-14,HY-15,HY-16,HY-17, HY-18,HY-19
SPS1	15	SP-13,SP-14,SP-15,SP-16
HYS5	14	HY-03,HY-36,HY-38,HY-39,HY-40,HY-41,HY-42, HY-45,HY-46,HY-47
HYS4	13	HY-32,HY-33
BLS2	12	BL-04,BL-16,BL-18,BL-19,BL-20,BL-23,BL-26,B-15
CIS3	11	CI-20,CI-21
MDS1[e]	10	MD-11,MD-13
HYS3[e]	10	HY-27,HY-31
BLS1[e]	10	BL-01,BL-14
RSS3	9	RS-22,RS-24
RSS1	9	RS-13 RS15[f]
MIS1[e]	9	-none-
HYS6[e]	9	CB-11
BLS3[e]	8	BL-27,BL-29,BL-30
BLS4[e]	8	CB-12

[a] Problem areas encompass all stations sampled in 1984 only in Segments HYS1, SIS1, CIS2, RSS2, RSS3, and possibly MDS1 (Station MD-12 in this segment was close to the AET for several chemicals).

[b] Total scores using the maximum rank method are summarized in Table 6.12. Segments are listed by decreasing magnitude of these scores.

[c] Stations shown have sediment concentrations (by various normalizations) of some chemical above its AET defined in Section 4. Biological data were not available for all stations listed.

[d] Station CI-18 may not be contained in the same problem area defined for the remainder of the Segment CIS1 stations listed.

TABLE 6.13 (Continued)

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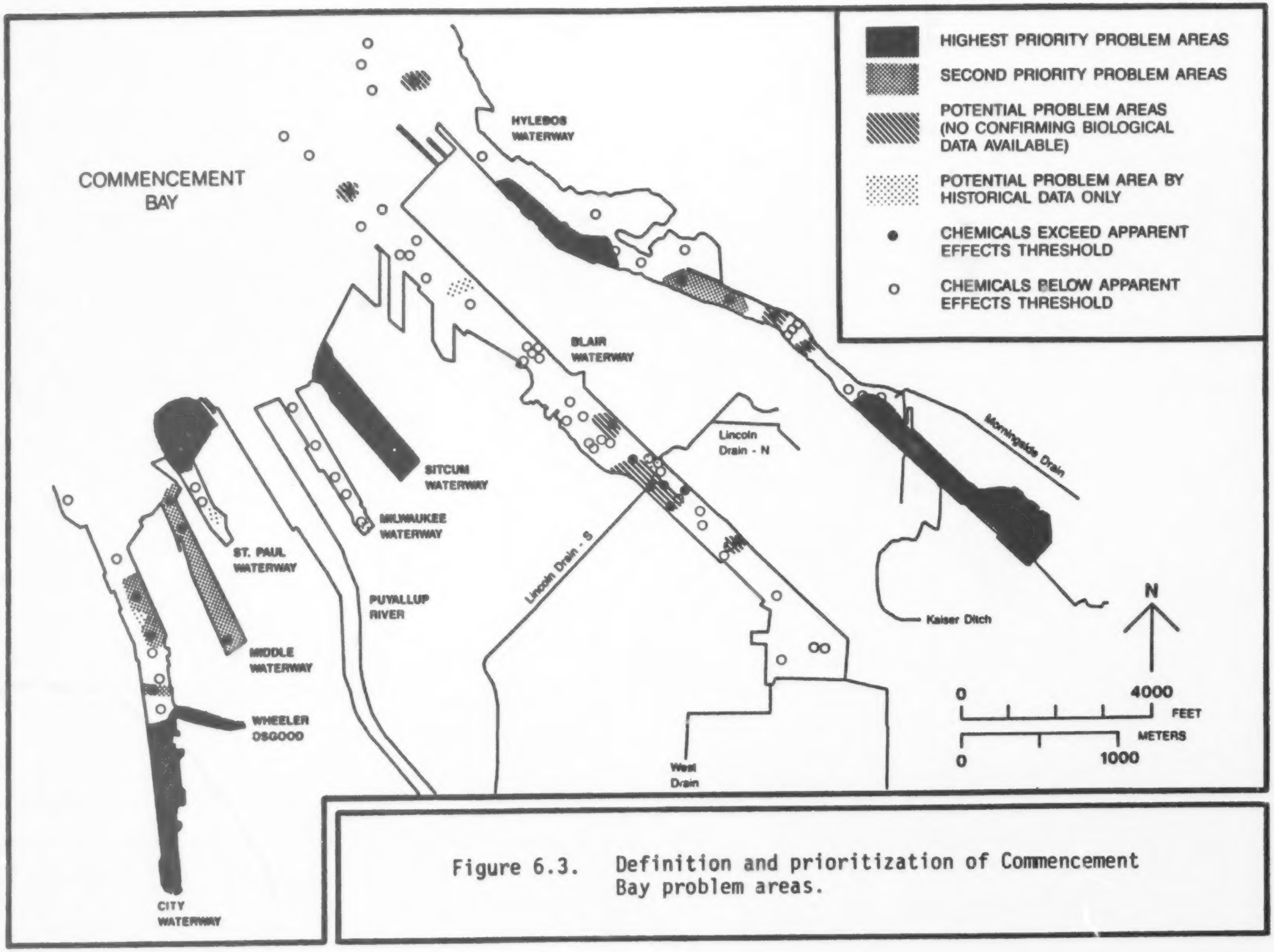
[e] No stations with biological data in these segments had sediment chemical concentrations exceeding their AET.

[f] This station had significant organic and metals contamination only when normalized to percent fine-grained material. There were no biological data available so no total toxicity-effects score has been determined. Station RS-15 is considered a separate potential problem area in Segment RSS1 from that defined by Station RS-13.



■ HIGHEST PRIORITY PROBLEM AREAS
▩ SECOND PRIORITY PROBLEM AREAS
▨ POTENTIAL PROBLEM AREAS (NO CONFIRMING BIOLOGICAL DATA AVAILABLE)
░ POTENTIAL PROBLEM AREA BY HISTORICAL DATA ONLY
● CHEMICALS EXCEED APPARENT EFFECTS THRESHOLD
○ CHEMICALS BELOW APPARENT EFFECTS THRESHOLD
COMMENCEMENT BAY
HYLEBOS WATERWAY
BLAIR WATERWAY
SITCUM WATERWAY
MILWAUKEE WATERWAY
ST. PAUL WATERWAY
PUYALLUP RIVER
MIDDLE WATERWAY
WHEELER OSGOOD
CITY WATERWAY
Lincoln Drain - N
Lincoln Drain - S
Morningside Drain
Kaiser Ditch
West Drain
N
0
4000
FEET
METERS
0
1000

Figure 6.3. Definition and prioritization of Commencement Bay problem areas.

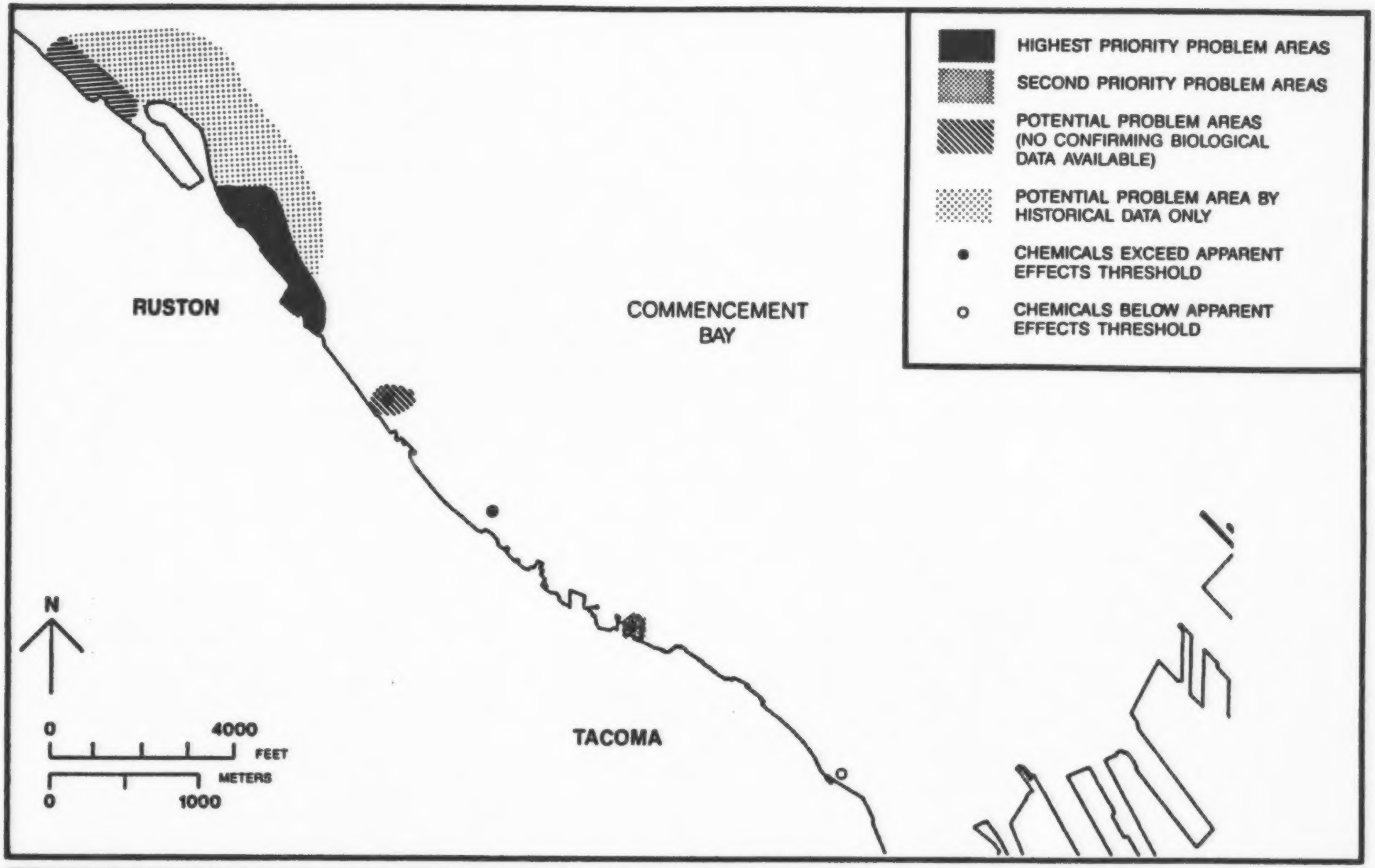

HIGHEST PRIORITY PROBLEM AREAS
SECOND PRIORITY PROBLEM AREAS
POTENTIAL PROBLEM AREAS (NO CONFIRMING BIOLOGICAL DATA AVAILABLE)
POTENTIAL PROBLEM AREA BY HISTORICAL DATA ONLY
CHEMICALS EXCEED APPARENT EFFECTS THRESHOLD
CHEMICALS BELOW APPARENT EFFECTS THRESHOLD
RUSTON
COMMENCEMENT BAY
TACOMA
N
0
4000
FEET
METERS
0
1000

Figure 6.3. (Continued).

Third priority sites included those where chemical contamination exceeded an AET, and one of the bioassays was significant or a single benthic taxon was significantly depressed in the problem area. Two problem areas received third priority for source evaluation, including one within each of Segment BLS2 in Blair Waterway and Segment RSS3 along the Ruston-Pt. Defiance Shoreline. Significant amphipod bioassay responses were observed at two stations in Milwaukee Waterway but no chemicals were found above their AET. As discussed in Section 4, these amphipod responses may have resulted from effects of grain size. The lowest priority sites for source evaluation included those where no sediment toxicity or benthic effects were observed, but where additional chemical data suggested that toxicity or benthic effects may have occurred at non-biological stations. The remaining six areas in Table 6.13 fell into this priority category, including two potential problem areas within Hylebos Waterway, three areas within Blair Waterway, and second potential problem area within Segment RSS1 on the eastern Ruston-Pt. Defiance Shoreline (Station RS-15). This latter area did not exhibit highly elevated concentrations of contaminants on a dry-weight basis, but AET were exceeded after the data were normalized to percent fine-grained material or organic carbon content.

Problem area boundaries shown in Figure 6.3 were extended, as appropriate, where historical data suggested that a problem existed. According to action-level guidelines in Table 6.8, amphipod toxicity data from Swartz et al. (1982) showing >50 percent response would identify historical problem sediments. Historical chemical concentrations that exceeded an AET were also considered appropriate for defining problem area boundaries. In general, these historical toxicity and chemical data reinforced current observations. The problem area in Segment HYS2 was expanded slightly as result of these comparisons, and historical high toxicity (>50 percent mortality) in the upper turning basin of Segment HYS1 reinforced a decision to extend the problem area to include the entire segment. High toxicity also was reported at the head of Milwaukee Waterway, at the Lincoln Avenue Drain on the north side of Blair Waterway, and at a drain near the head of St. Paul Waterway. Present data for sediments near these locations did not indicate a problem.

Source evaluations are recommended for at least the 14 problem areas in priority categories 1, 2, and 3 discussed in this section.

6.4 CHEMICAL CHARACTERIZATION OF PROBLEM AREAS

This section summarizes chemical characteristics of the 14 problem areas recommended for source evaluation (Section 6.4). Chemical characteristics of the remaining problem areas also are summarized briefly. This analysis was conducted 1) to identify chemicals present at high concentrations within each problem area and 2) to identify chemicals that appear either to distinguish problem areas from one another or to establish apparent relationships among them. In Section 6.5, quantitative relationships among contaminants, sediment toxicity, and biological effects are used to prioritize potential problem chemicals in each problem area.

To provide a reasonably consistent data set for comparing the chemistry of problem areas, the analysis is based primarily upon data from the March, 1984 sediment survey. These data were collected synoptically using similar procedures, and were analyzed by the same laboratory, therefore, they should have the lowest intra-sample variance due to other factors besides field variability. Distributions of the measured chemicals also reflect those of unmeasured chemicals from similar sources and results must be interpreted within this context.

6.4.1 Hylebos Waterway

Two high priority problem areas were identified within Segments HYS1 and HYS2 of upper Hylebos Waterway. The entire reach of upper Hylebos Waterway was highly contaminated with HPAH and most of the metals, although the concentrations of only some metals exceeded toxicity or benthic effects AET. Distributions of these chemicals were not clearly separated between the two segments. Both groups of substances (especially HPAH) exhibited high EAR near two sites, one along the south side of the channel at Stations HY-15 and HY-16, and a second on the south side at Station HY-22. Compositional differences in the HPAH and LPAH between these two sites indicated that the PAH did not necessarily originate from the same source. Compositional similarities were generally too weak to establish a clear relationship between the HPAH at the sites, supporting the definition of two problem areas. Metals in the sediments of upper Hylebos Waterway exhibited a general spatial distribution similar to that of the PAH. Arsenic and copper were present at relatively high levels compared to those of the other metals, but only arsenic was present at concentrations above toxicity or benthic effects AET. Although this composition was not observed at most stations in Commencement Bay, it was characteristic of some sediments along the Ruston-Pt. Defiance Shoreline, as discussed in Section 6.4.8. PCB and chlorobenzene concentrations were elevated above AET only in the Segment HYS2 problem area, distinguishing this problem area from that in Segment HYS1. Sediments from Station HY-27 in Segment HYS3 also contained high PCB concentrations that exceeded toxicity AET. There was no evidence that the problem area in Segment HYS2 extended to include the "hot spot" in Segment HYS3.

A "hot spot" problem area was identified in Segment HYS4 of Hylebos Waterway, east of the 11th Street Bridge (Stations HY-32 and HY-33). This segment included a long reach of waterway with few sampling stations. Concentrations of metals and chlorinated compounds in this area increased toward adjacent segments, indicating that advective transport from outside of the segment may have contributed many of these substances. The PAH, however, exhibited high EAR at Station HY-33, and decreased in concentration with distance from this station. HPAH at Station HY-33 were unique because of the high EAR for benzo(a)pyrene compared to those of other HPAH. Finally, 4-methylphenol was present at Station HY-33 at the highest EAR observed for that compound in Hylebos Waterway. This concentration did not exceed either the toxicity or benthic effects AET. Sediment concentrations appeared to show a decreasing gradient with distance from Station HY-33. While sediment from this problem area generally did not contain chemicals with high EAR, gradients for the PAH and 4-methylphenol indicated presence of a nearby source. The limits of the "hot spot" were poorly defined, but could have extended from approximately the 11th Street Bridge east to Station HY-32.

A high priority problem area was identified in Segment HYS5, west of the 11th Street Bridge. While cross-channel sampling was limited, sediments from the southern side of the waterway appeared to be more contaminated than those from the middle or north side. A single sample from the large shallow area on the north shore (HY-02) indicated that this area was uncontaminated (i.e., no concentrations exceeded the range of concentrations observed in any Puget Sound reference area). Anomalously low EAR for all chemicals were measured at Station HY-44. The simplest explanation is that this station contained relict sediments either dumped at the site in a dredging operation or exposed by ship scour. Concentrations of the majority of the chemicals measured in sediments along the south shore were not greatly elevated above reference conditions, although selected chlorinated compounds were present in the highest concentrations observed throughout Commencement Bay. Their spatial distributions were not as simple as might have been expected if all compounds had originated from a single source. Intertidal and shallow subtidal sediments along the southern shore about 3,000 feet from the waterway mouth were highly contaminated with chlorinated ethenes. The concentrations of these compounds sometimes eceeded toxicity and benthic effects AET by several orders of magnitude. These very high contaminant levels were restricted to the nearshore area, and declined rapidly with distance offshore and alongshore. Chlorinated butadiene concentrations exhibited the strongest single gradient, maximizing at Stations HY-43, HY-46, and HY-47 (all contiguous nearshore stations on the south side of the channel). Only concentrations of HCBD exceeded AET in this area. Concentrations of a tentatively identified pentachlorocycolpentane isomer and many of the chlorinated benzenes were elevated above AET at Station HY-46 and also at Station HY-36, near the 11th Street Bridge. PAH concentrations were also elevated near the 11th Street Bridge.

6.4.2 Blair Waterway

Blair Waterway was relatively uncontaminated in comparison with most other areas examined in Commencement Bay. Sediment toxicity was only observed at two stations in Segment BLS2 from Lincoln Avenue Drain to the 11th Street Bridge. In general, chemicals in Blair Waterway sediments were either uniformly or patchily distributed. Concentrations of 4-methylphenol exhibited an apparent gradient from a maximum near Lincoln Avenue to a minimum toward the mouth of the waterway. In contrast, 2-methoxyphenol showed an opposite gradient, indicating possible advective transport into this reach from areas near the mouth of the waterway. Pentachlorophenol was found in high concentration at two stations in Blair Waterway (Stations BL-18 and BL-30) but was not detected in the surrounding sediments. Probably the most unique feature of sediments in Segment BLS2 was the high EAR for 1,3-dichlorobenzene. While much higher EAR were observed for other chlorinated benzenes in other study areas, the highest concentrations of 1,3-dichlorobenzene were found in Segment BLS2. A clear gradient of decreasing concentrations was observed in this segment from a maximum at Station BL-19 in the middle portion of the waterway to a minimum near the mouth. High concentrations were also found in sediments from the south side of the waterway in Segment BLS2 (BL-19, BL-20, BL-21, and BL-24). Pentachlorophenol and 1,3-dichlorobenzene were detected in sediments from only a few other locations in Commencement Bay. There were insufficient biological stations with high concentrations of these compounds to determine their AET for the study area. A potential problem area defined by these compounds may extend from about 1,000 ft east to 500 ft west of Lincoln Avenue in mid-Blair Waterway. This potential problem area does not have a high priority for source evaluation.

6.4.3 Sitcum Waterway

A high-priority problem area was defined for all of Sitcum Waterway. Bioaccumulation of PCBs in fish muscle tissue and a high prevalence of hepatic neoplasms were major factors that increased the ranking of this problem area relative to others. Sitcum Waterway sediments differed from those in neighboring waterways primarily in the much higher EAR for essentially all of the metals. Based on the most recent samples, metals were present at high EAR at the head of the waterway and decreased in concentration toward the mouth. A more patchy distribution of metals is indicated by historical data. In consideration of all available data, no trends are evident. However, the concentrations of several metals in both data sets exceed AET (i.e., arsenic, copper, lead, and zinc). The relative concentrations of arsenic, copper, lead, and zinc in Sitcum Waterway sediments were similar to those measured in sediments from the head of City Waterway, except that arsenic and copper were slightly more enriched in Sitcum Waterway. Most of the organic compounds were present at low EAR compared with those in many other areas of Commencement Bay. Both the LPAH and HPAH had two maxima, one near the head of the waterway in conjunction with the high EAR for metals, and one near the mouth at Station SI-14. PCBs were detected in Sitcum Waterway sediments but concentrations did not exceed either the 80th percentile value for all of Commencement Bay sediments or the toxicity or benthic effects AET for PCBs.

6.4.4 Milwaukee Waterway

Milwaukee Waterway was one of the least contaminated areas sampled in Commencement Bay. The waterway was considered a potential problem area primarily because of consistently high accumulations of naphthalene in fish muscle tissues (typically >1,000 ug/kg wet weight), a significant prevalence of liver lesions, and sediment contamination exceeding Puget Sound reference area conditions. Elevations of metals in Milwaukee Waterway sediments were uniformly low. LPAH concentrations decreased slightly from the head of the waterway to the mouth, and were the only U.S. EPA priority pollutants with concentrations that exceeded the 80th percentile value for all Commencement Bay sediments. Concentrations of 2-methoxyphenol (tentative identification) were high at most stations, possibly representing material transported from St. Paul Waterway (see Section 6.4.5). Most of the phenols and chlorinated benzenes (primarily 1,4-dichlorobenzene) had low EAR and no clear spatial trends in Milwaukee Waterway. Detectable quantities of 1,3-dichlorobenzene, a comparitively rare compound in Commencement Bay, were found in the waterway sediments. No substances with high EAR were observed, and the substances that were detected did not exhibit hot spots, gradients, or other trends that would indicate a major source in the waterway. No chemicals exceeded their toxicity or benthic effects AET in Milwaukee Waterway.

6.4.5 St. Paul Waterway

A high-priority problem area was defined near the mouth of St. Paul Waterway. Sediment contamination in this problem area differed considerably from that in all other Commencement Bay areas. None of the HPAH, PCBs, metals, or chlorinated benzenes were particularly enriched at the site, except for limited copper enrichment (below its AET) at Station SP-14, off the outfall of the Champion International pulp mill. Methylated phenols (especially 4-methylphenol) and LPAH were the characteristic contaminants found in the problem area. Concentrations of these compounds all exceeded toxicity and benthic effects AET near the outfall and decreased abruptly away from the outfall. Many additional hydrocarbon and substituted phenols were probably present in these sediments but were not directly measured. It was apparent from the data from St. Paul and adjacent waterways that at least 2-methoxyphenol had been transported to other areas of Commencement Bay.

6.4.6 Middle Waterway

All of Middle Waterway was defined as a second-priority problem area. Contaminants present in high concentration included copper, arsenic, mercury, PAH, substituted phenols, and chlorobenzenes. Pentachlorophenol was detected at the head of the waterway (Station MD-11) at 620 ug/kg DW. This concentration was similar to that at two stations in Blair Waterway. These three stations were the only Commencement Bay stations where pentachlorophenol concentrations exceeded 150 ug/kg DW. There were no biological data available from any of these stations, which limited the analysis of AET for pentachlorophenol. Few other areas in Commencement Bay had as much diversity in the spectrum of compounds present at high EAR. Concentrations of copper, arsenic, and mercury increased regularly from the head to maximum values near the mouth (Station MD-13), while lead (and to a lesser extent zinc) concentrations peaked in the middle of the waterway at Station MD-12. The EAR of copper, arsenic, and mercury were among the highest observed in this study beyond Segment 2 of the Ruston-Pt. Defiance Shoreline, although arsenic concentrations were below toxicity and benthic effects AET. Copper and mercury values exceeded their AET at Station MD-13.

LPAH decreased slightly in concentration from the head to the mouth of Middle Waterway. LPAH (and HPAH) concentrations exceeded toxicity and benthic effects AET only at Station MD-11. The highest concentration of PAH in either the present or historical data set was found at this station. The composition of these PAH was similar to that observed in City Waterway, with naphthalene, 2-methylnaphthalene, and phenanthrene exhibiting the highest EAR. HPAH also decreased in concentration from the head to the mouth of the waterway but the composition differed along the waterway. HPAH in sediments near the head and the mouth of the waterway were dominated by pyrene and benzo(a)pyrene and had low levels of methylpyrenes. Similar relative concentrations were observed in the Wheeler-Osgood branch of City Waterway. Sediments from Station MD-12 in the center of the waterway had higher relative concentrations of methylpyrenes and benzo(a)pyrene than sediments from the other stations. The relative composition of these compounds at MD-12 was simlar to that noted in sediments from Station CI-17 in the middle of City Waterway.

6.4.7 City Waterway

Two high-priority problem areas were defined in City Waterway, one at the head of the main channel of the waterway, and a second within the Wheeler-Osgood branch. High EAR for aromatic hydrocarbons, chlorobenzenes, some metals, and phenols were found in both problem areas. Concentrations of these substances also exceeded toxicity and benthic effects AET in these areas. Within the waterway, lead exhibited one of the most consistent concentration gradients of any substance in any Commencement Bay study area. Sediment lead concentrations at the head of the waterway were among the highest observed beyond Segment 2 of the Ruston-Pt. Defiance Shoreline. Lead concentrations decreased regularly from a maximum at Station CI-11 to levels comparable with the remaining study area toward the mouth of the waterway. A similar gradient in percent organic carbon was observed from the head of the waterway to the mouth. PAH concentrations generally decreased from the head of the waterway along the main channel of City Waterway. Maximum PAH concentrations were observed at Station CI-12 rather than CI-11. Chlorinated benzenes, especially 1,4-dichlorobenzene, were found at high concentration in the main channel of City Waterway at the head of the waterway only.

EAR for metals and HPAH in the Wheeler-Osgood problem area were comparable to those at adjacent stations in the main channel. Selected chlorobenzenes and 4-methylphenol were found at high concentrations in this problem area, with clear gradients of decreasing concentrations with distance from the Wheeler-Osgood branch in the main city waterway channel. These latter compounds distinguished Wheeler-Osgood from the rest of City Waterway. The full extent of the possible contamination is uncertain because of the limited number of samples collected.

A potential hot spot including Stations CI-20 and CI-21 was defined near the mouth of City Waterway. High levels (but below AET) of 2-methoxyphenol were present in sediments from the mouth of the waterway, and may have resulted from transport into the waterway from the St. Paul Waterway problem area. With the exception of PAH, which were elevated in this area above their toxicity and benthic effects AET, most other chemicals detected appeared to be part of a gradient of decreasing concentrations from the middle and head of City Waterway.

6.4.8 Ruston-Pt. Defiance Shoreline

Sediments within Segment RSS1 of the Ruston-Pt. Defiance Shoreline were not extensively sampled, but a single station was found to have high EAR for a few chemicals in an area of otherwise low concentrations. The concentration gradients observed along the shoreline for most substances (i.e., PCBs, metals, and at least some of the substituted phenols) were consistent with transport from other areas as the dominant source of contamination. PAH and 1,4-dichlorobenzene concentrations were elevated at Station RS-13. An accurate estimate of the spatial extent of the contaminated area near RS-13 was not possible because of limited sampling.

The most extreme metals contamination in Commencement Bay was found in the high-priority problem area defined within Segment RSS2. Contamination of all metals in this problem area was highest at stations directly off the three outfalls of the ASARCO smelter. It is unclear whether one large or three smaller, nearshore "hot spots" were present, because samples between the outfalls were not collected. Concentrations of metals decreased rapidly both alongshore (toward Stations RS-16 and RS-24) and offshore (toward Station RS-19 and RS-20). The metals contamination in the "hot spot" defined within Segment RSS3 off of Pt. Defiance is believed to be associated exclusively with slag or spilled ore, because of the granular nature of the sediment. If the high concentrations found in the problem area within Segment RSS2 were also associated with the smelter slag or ores, then the spatial extent of the contaminated area could be defined by the physical presence of slag or ores. However, the high EAR were likely associated with an effluent component, so the area of extreme EAR associated with this source may be limited to near the main outfalls. The defined problem area was also highly contaminated with a number of organic compounds, including PAH, PCBs, and 1,4-dichlorobenzene. The spatial distribution of these compounds was not as uniform as observed for the metals, but showed variable maxima at each outfall station. The contaminated area probably extended east from Segment RSS2 some distance along the shore but did not extend to Station RS-15.

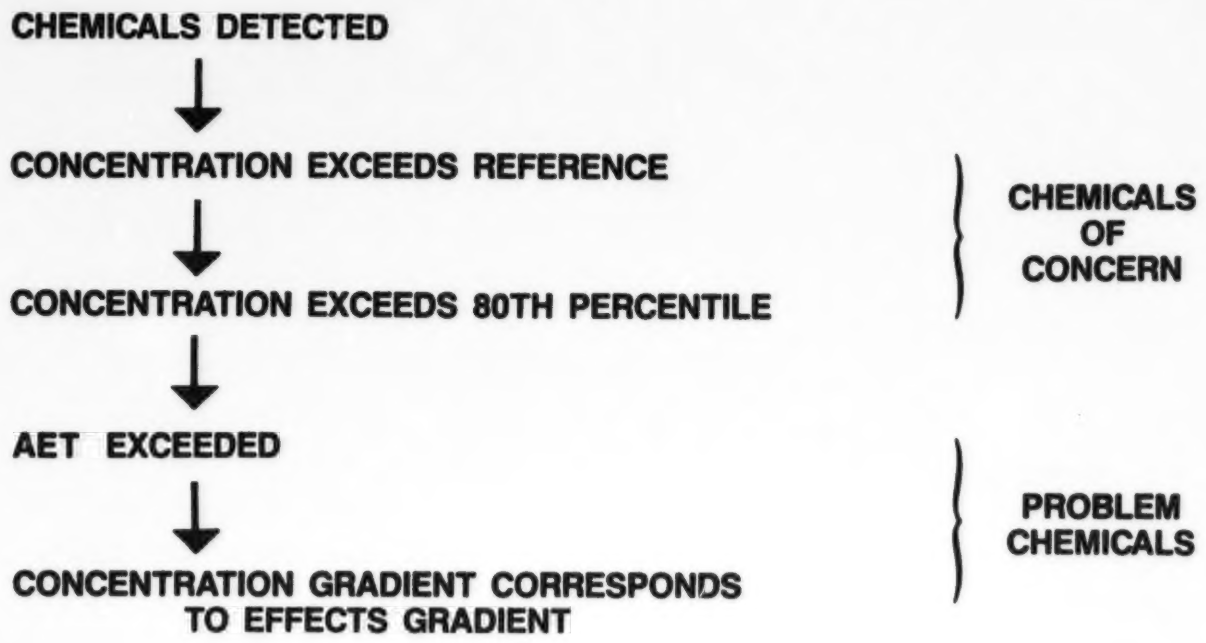
6.5 RANKING OF POTENTIAL PROBLEM CHEMICALS IN PROBLEM AREAS

The previous section described the distributions of major chemical contaminants that helped distinguish problem areas. This section integrates results from quantitative relationships developed in Section 4 to prioritize potential problem chemicals identified in each problem area. The approach used to reduce the possible list of problem chemicals is shown in Figure 6.4. Chemicals that were undetected in a problem area were eliminated from consideration as problem chemicals. Some chemicals were detected sporadically. The detection limit attained for these chemicals was always lower than the apparent effect thresholds determined in Section 4.1.

Chemicals of concern were defined in Section 3.1 as chemicals with concentrations exceeding all Puget Sound reference conditions. These chemicals were not necessarily considered problem chemicals associated with environmental effects, because most sediments in Commencement Bay were contaminated above reference conditions and only some of these sediments exhibited toxicity or benthic effects. As shown in Figure 6.4, chemicals detected at concentrations that exceeded 80 percent of the values determined for all Commencement Bay stations were of greater concern. Source evaluations may be conducted by WDOE when sediments exceed this level of contamination, even if toxicity or biological effects are not observed (e.g., Table 6.8 Action-Level Guidelines).

In all cases, the 80th percentile value for chemicals in Commencement Bay was lower than the apparent effect threshold defined in Section 4.1. These thresholds reflected the observation that high levels of some contaminants were found in sediments that exhibited no observable toxicity or benthic effects. Because the apparent effect threshold was defined at the contaminant concentration above which toxicity or benthic effects were always observed, chemicals present above the threshold are potential problem chemicals (Figure 6.4). Apparent effect thresholds were established for each chemical based on a data set that included all stations where synoptic chemical, toxicity, and benthic effects data were collected. For sediments that had no corresponding toxicity or benthic effects data, it was assumed that these same apparent effect thresholds could be applied to the available chemical data as predictors of potential problem sediment conditions.

Finally, the highest priority chemicals shown in Figure 6.4 are those that were present above an AET in a problem area and that also exhibited a concentration gradient corresponding to observed changes in toxicity



CHEMICALS DETECTED
CONCENTRATION EXCEEDS REFERENCE
CONCENTRATION EXCEEDS 80TH PERCENTILE
AET EXCEEDED
CONCENTRATION GRADIENT CORRESPONDS TO EFFECTS GRADIENT
CHEMICALS OF CONCERN
PROBLEM CHEMICALS

Figure 6.4. Prioritization of chemicals.

or benthic effects. For example, a strong linear relationship was found between sediment toxicity in Hylebos Waterway and PCB concentrations (Section 4.2.3). Other contaminants were found above apparent effect thresholds in the same problem area but none showed as strong a relationship with the observed toxicity. Therefore, PCBs are potential problem chemicals with the highest priority for source evaluation in that problem area because they have a demonstrated correspondence with the observed toxicity. Some unidentified contaminant with a similar distribution as the PCBs may have been the actual problem chemical. Source identification for PCBs would still be recommended based on the assumption that the problem chemical came from the same source, and that corrective action at the source may effectively control its release.

Potential problem chemicals in each problem area defined in Table 6.13 are summarized in Table 6.14. Problem areas identified within each segment listed are ordered in descending rank. Three priorities of chemicals are given for each problem area. Priority 1 chemicals were present above an AET and their distributions corresponded with gradients of observed toxicity or benthic effects. Priority 2 chemicals were also above an AET in the problem area, but these chemicals either showed no particular relationship with gradients of observed toxicity or benthic effects, or insufficient data were available to evaluate their correspondence with gradients. Chemicals with concentrations that were predicted to be above apparent effect thresholds at non-biological stations were placed no higher than Priority 2 because of the lack of biological data. Finally, chemicals with concentrations above apparent effect thresholds at only one station within the problem area are shown in Table 6.14 as Priority 3. Problem areas that were small hot spots often had chemical contamination that exceeded apparent effect thresholds at only one station. A fourth category of chemicals not shown in Table 6.14 consisted of all other chemicals with concentrations in the problem area that exceeded the 80th percentile value for all Commencement Bay sediments but did not exceed an apparent effect threshold. All measured chemicals with concentrations (DW) that exceeded the 80th percentile criteria were summarized in Table 3.15 in at the end of Section 3.

Within each priority group in Table 6.14, chemicals are listed in descending order of their "toxicity significance factor" (TSF) when a factor could be determined. Available toxicity significance factors for these chemicals or chemical groups are listed in Appendix I. These TSF factors represent a combined index of the potential mammalian toxicity resulting from the consumption of contaminated seafood and the potential for contaminant uptake by indigenous organisms. The order of chemicals within a priority group therefore reflects a first-order approximation of their relative health hazard.

Priority 1 chemicals were identified in six of the eight highest priority problem areas (i.e., problem areas exhibiting significant contamination, toxicity, and benthic effects as well as significant bioaccumulation or liver lesions in English sole). These chemicals included:

- Mercury, lead, zinc, and arsenic
- PCBs, 4-methylphenol, LPAH, and HPAH.

TABLE 6.14. POTENTIAL PROBLEM CHEMICALS IN PROBLEM AREAS

Segment Containing Problem Area[a] (in rank order)	Potential Problem Chemicals[b]	
CIS1	Priority 1:	Hg, Zn, Pb [TOC[d]][c]
	Priority 2:	HPAH, Cd, Ni, Cu, LPAH, 2-methylphenol, 4-methylphenol, phthalate esters [oil & grease][c]
	Priority 3:	dichlorobenzenes, N-nitrosodiphenylamine, [aniline, benzyl alcohol][c]
HYS2	Priority 1:	PCBs
	Priority 2:	HPAH, Ni, As, tetrachloroethene [Hg[e], Cu[e], Zn[e], Pb[e] (intertidal sediments only)]
	Priority 3:	HCBD, chlorinated benzenes, phthalate esters, phenol [benzyl alcohol, dibenzothiophene, methylphenanthrenes, methylpyrenes][c]
CIS2	Priority 1:	none
	Priority 2:	HPAH, Cd, Cu[e], Zn, dichlorobenzenes, LPAH[e], Pb, N-nitrosodiphenylamine, 4-methylphenol, phenol [biphenyl, TVS, TOC, oil & grease][c]
RSS2	Priority 1:	Hg, As, LPAH
	Priority 2:	HPAH, PCBs, Cd, Ni, Cu, Zn, Pb, Sb [dibenzofuran][c]
	Priority 3:	dichlorobenzenes, N-nitrosodiphenylamine, 2-methylphenol, 4-methylphenol, phthalate esters, [1-methyl-(2-methylethyl)benzene, biphenyl, dibenzothiophene, methylphenanthrenes, retene, methylpyrenes][c]
SIS1	Priority 1:	none
	Priority 2:	As[e], Cu[e], Zn, Pb
	Priority 3:	N-nitrosodiphenylamine [dibenzofuran, 1-methyl-(2-methylethyl)benzene, diterpenoid hydrocarbons][c], LPAH, HPAH
HYS1	Priority 1:	HPAH, As, Zn (limited evidence of a gradient for each with one or more toxicity/effects indicator)
	Priority 2:	phenol, Sb
	Priority 3:	Phthalate esters, ethylbenzene, tetrachloroethene, [xylenes, 1-methyl-(2-methylethyl)benzene, methylpyrenes, TVS][c]
SPS1	Priority 1:	4-methylphenol
	Priority 2:	[benzyl alcohol, 1-methyl(2-methylethyl)benzene, 2-methoxyphenol][c]
	Priority 3:	Ni, LPAH, 2-methylphenol, phenol [biphenyl, diterpenoid hydrocarbons, retene, TVS, TOC][c]

TABLE 6.14. (Continued)

HYS5	Priority 1:	PCBs
	Priority 2:	HCBD, chlorinated benzenes, chlorinated ethenes [pentachlorocyclopentane isomer][c], Pb
	Priority 3:	Hg, HPAH[e], Cu[e], Zn[e], LPAH[e], phenol [benzyl alcohol, biphenyl][c]
HYS4 (hotspot)	Priority 1:	none
	Priority 2:	none
	Priority 3:	HPAH[e], PCBs[e], HCBD, LPAH[e], N-nitrosodiphenylamine [benzyl alcohol, dibenzofuran[e], pentachlorocyclopentane isomer, methypyrenes][c]
BLS2 (no action)	Priority 1:	none
	Priority 2:	dichlorobenzenes, N-nitrosodiphenylamine, 4-methylphenol, phenol
	Priority 3:	As, HCBD, pentachlorophenol, 2-methylphenol, oil & grease
CIS3 (hotspot)	Priority 1:	none
	Priority 2:	HPAH, LPAH
	Priority 3:	PCBs[e], Zn[e], phenol [biphenyl, dibenzothiophene][c]
MDS1	Priority 1:	none
	Priority 2:	Hg, Cu
	Priority 3:	HPAH, As, Zn, dichlorobenzenes, LPAH, pentachlorophenol, Pb, 4-methylphenol, phenol [dibenzothiophene, diterpenoid hydrocarbons, methylpyrenes][c]
HYS3 (no action)	Priority 1:	none
	Priority 2:	PCBs, As, Zn
	Priority 3:	n-Nitrosodiphenylamine
BLS1 (no action)	Priority 1:	no toxicity/effects observed at stations tested
	Priority 2:	none
	Priority 3:	HPAH, phenol
RSS3 (hot spot)	Priority 1:	none
	Priority 2:	As, Cd, Cu, Zn, Pb, N-nitrosodiphenylamine, Sb
	Priority 3:	none
RSS1 (hot spots)	Priority 1:	none
	Priority 2:	none
	Priority 3:	Station RS-13 hotspot: HPAH, dichlorobenzenes, LPAH, 2-methylphenol, 4-methylphenol [dibenzofuran, biphenyl, methylphenanthrenes, retene, methylpyrenes][c] Station RS-15 hotspot: As, HCBD, Cd, Ni, Cu, Zn, phenol (these chemicals exceed AET at RS-15 only after normalization to percent fine-grained material or to organic carbon content)

TABLE 6.14. (Continued)

MIS1 (no action)	No chemicals found above apparent effect levels at stations sampled in Milwaukee Waterway	
HYS6 (no action)	Priority 1:	no toxicity/effects observed at station tested
	Priority 2:	none
	Priority 3:	phthalate esters
BLS3 (no action)	Priority 1:	no toxicity/effects observed at stations tested
	Priority 2:	none
	Priority 3:	pentachlorophenol, 2-methylphenol, 4-methylphenol
BLS4 (no action)	Priority 1:	no biological data available
	Priority 2:	none
	Priority 3:	phthalate esters

[a] See Table 6.13 for ranking of problem areas. Problem areas encompass all stations sampled in 1984 only in Segments HYS1, SIS1, CIS2, RSS2, RSS3, and possibly MDS1 (Station MD-12 in this segment was close to apparent effect thresholds for several chemicals).

[b] Concentrations of these chemicals exceeded an apparent effect threshold (by various normalizations) in sediment from at least one station in the defined problem area. Chemicals are listed in each priority group in descending order of their calculated toxicity significance factor, if available. Stations with and without biological data area included. Priority 1 chemicals showed a concentration gradient with toxicity or biological effects gradients. Priority 2 chemicals were above apparent effect thresholds at more than one station within the problem area, but either no gradient corresponding to that for toxicity/effects was observed, or no biological data were available to assess gradients. Priority 3 chemicals were above apparent effect thresholds at one station only within the problem area.

[c] Toxicity significant factors were not available for the chemicals listed in brackets. These chemicals have not been prioritized relative to other chemicals in the same priority group.

[d] TOC concentrations did not exceed an AET in the problem area defined in Segment CIS1 but the TOC concentration gradient corresponded with observed changes in effects (e.g., sediment toxicity). This correspondence may result from the covarying distribution of TOC with other contaminants, including lead and zinc.

[e] Chemical elevated above an AET in the defined problem area only on the basis of historical data.

All of these chemicals are recommended for source evaluation. Priority 1 chemicals were not identified in any of the remaining twelve problem areas with lower priorities for source evaluation. For 10 of these areas, there were not enough stations to establish correspondence between toxicity or benthic effects and sediment contamination.

Priority 2 chemicals were identified in all eight of the highest priority problem areas. Priority 2 chemicals were also identified in three of the problem areas with lower priorities for source evaluation (i.e., problem areas within Segments BLS2, CIS3, and RSS3). In addition to the chemicals listed as Priority 1, these included:

- Cadmium, nickel, and antimony
- HCBD, chlorinated benzenes, chlorinated ethenes, phenol, 2-methylphenol, N-nitrosodiphenylamine, dibenzofuran, and selected phthalate esters (e.g., bis-(2-ethylhexyl) and di-n-butyl phthalates)
- Selected tentatively identified compounds.

These chemicals are recommended for source evaluation where sufficient spatial data are available to indicate sources. Priority 3 chemicals were identified in each problem area except Milwaukee Waterway and Segments CIS2 (City Waterway) and RSS3 (Pt. Defiance-Ruston Shoreline). The latter two problem areas had no Priority 3 chemicals because all potential problem chemicals were elevated at more than one station in the problem area. The potential problem area in Milwaukee Waterway had no chemicals elevated above an AET. Priority 3 chemicals not already included in the Priority 2 group are: pentachlorophenol, aniline, and selected tentatively identified compounds. These chemicals are not recommended for source identification unless their occurrence at a single station in a problem area is associated with a potential source that is not necessarily indicated by other chemicals (e.g. pentachlorophenol in the problem area within Segment BLS2). Priority 2 and 3 chemicals with spatial distributions that are poorly defined are still recommended for potential source identification when additional concern has been placed on their potential for effects in fish (e.g., accumulations of benzyl alcohol in fish livers discussed in Section 4.6.2).

Chemicals present below apparent effect thresholds but above the 80th percent value for all Commencement Bay sediments are recommended for source identification when they appear to be highly characteristic of a particular problem area and potential sources (e.g., TOC at the head of City Waterway).

6.6 SUMMARY

Fourteen problem areas (including isolated "hot spots") were recommended for priority source evaluation. The remaining 7 of the total 21 problem areas identified were not recommended for high priority source evaluation. Six of these lowest priority areas contained stations where contaminant concentrations exceeded AET, but no confirming biological data were available. The seventh area not recommended for priority source evaluation (Milwaukee Waterway) contained no chemicals measured above their AET.

Potential problem chemicals of varying priorities for source identification were also identified in each of the 14 areas recommended for priority source evaluation. Eight problem areas have the highest priority for immediate source evaluation. These problem areas are located in Hylebos, City, Sitcum, and St. Paul Waterways and along the Ruston-Pt. Defiance Shoreline. Eight problem chemicals were identified in six of these latter problem areas that have the highest priority for source identification because of apparent correspondences with observed toxicity or benthic effects.